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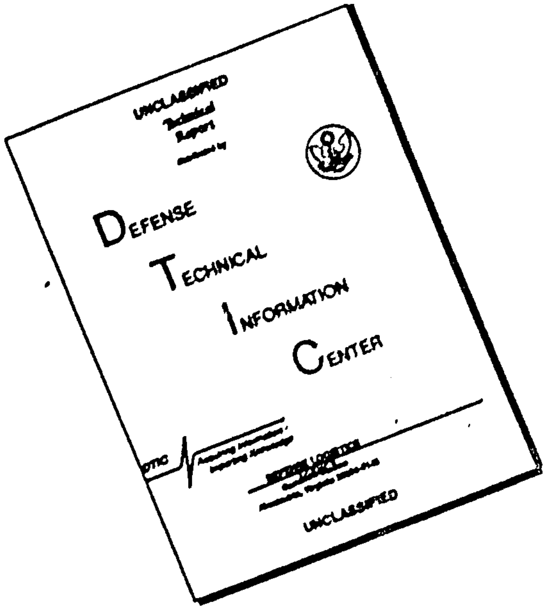

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U. S. NAVY
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WASHINGTON, D. C.

16 August 1957

Report No. 1307

(Semiannual)

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(TITLE UNCLASSIFIED)

UNDERWATER PROPULSION DEVICES

Contract Nonr-1863(00)

★

Underwater Engine Division

Aerojet-General CORPORATION
SUBSIDIARY OF THE GENERAL TIRE & RUBBER COMPANY

THE GENERAL TIRE

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16 August 1957

Report No. 1307
(Semiannual)

GENERAL RESEARCH IN THE FIELD OF UNDERWATER PROPULSION DEVICES AND ASSOCIATED EQUIPMENT

Contract Nonr 1863(00)

Written by:

L. B. Kelly
R. M. Viney

No. of Pages: 81

Period Covered:

6 December 1956 through 5 June 1957

Approved by:

for C. A. Gongwer, Manager
Underwater Engine Division

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AEROJET-GENERAL CORPORATION

Azusa, California

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CONTRACT FULFILLMENT STATEMENT

This semiannual report is submitted in partial fulfillment of Contract Nonr 1863(00) and covers the period from 6 December 1956 through 5 June 1957.

I. OBJECTIVE

The purpose of this program is to conduct general research in the field of underwater propulsion devices and associated equipment. During the period covered by this report, work was performed on several different types of underwater propulsion devices.

A. The first phase of the program is concerned with establishing the design of the free-running Alclo hydroductor by suitable static and dynamic tests so that the depth insensitivity of the hydroductor can be proved.

B. The second phase of the program was to complete a theoretical investigation of the power-plant parameters for a small high-speed submarine. This feasibility study program was made to determine the general configuration, by including sizes and weights, of the major components of an approximately 2000-shp submarine power plant using 90% concentrated hydrogen peroxide, diesel fuel, and sea-water diluent. The application of an exhaust-condensing system to this power plant was also to be studied.

C. The third phase of the program is to continue an investigation of sea water used as a diluent in small engine systems using concentrated hydrogen peroxide and fuel oil or alcohol. Further literature survey of work accomplished by other agencies is to be conducted. New methods for the use of sea-water diluent are to be devised, investigated, and tested.

II. SUMMARY

A. HYDRODUCTOR

Development effort has been continued on the external-condensing hydroductor models. Test data was obtained using the Model X3 hydroductor on the rotating boom under conditions that yield a range of cavitation numbers from .052 to .476. Microflash photographs were made of some of the models under test to correlate the flow patterns with the performance data. The models tested without an afterbody did not show performance as satisfactory as the Model X3 with the afterbody.

B. SUBMARINE POWER PLANT FEASIBILITY STUDY

This study program was completed and the results presented in Reference 1. These results show that a small chemical power plant using diesel fuel and 90% concentrated hydrogen peroxide as the propellants with sea-water diluent is feasible for use in a small high-speed submarine. The performance of such an arrangement with a condensing system on the turbine exhaust was calculated to be 6.29 lb of expendibles per shaft horsepower hour at the surface and 7.04 lb of expendibles per shaft horsepower hour at 1000 ft depth. All the major components for a 1900-shp power plant can be housed in a space 3 ft in diameter by 3 ft long.

C. SEA-WATER DILUENT PROGRAM

The use of sea water instead of fresh water as the diluent for hydrogen peroxide engines would potentially improve the performance of these engines in torpedoes and other underwater vehicles. This program was planned to supplement previous efforts to investigate and determine the techniques for using sea water as a satisfactory diluent. Among the approaches to the problem which were investigated were:

1. Addition of small quantities of chemicals to the sea water or fuel to change the nature of the solids formed, so that deposits will not occur or can be readily flushed away.

2. Cationic-exchange treatment of the sea water and determination of the required size of the ion exchange cartridge design.

Tests were conducted using the 70% E hydrogen peroxide and 92.5% ethyl alcohol, as well as 90% concentrated hydrogen peroxide and diesel fuel. Combustion temperatures covered a range from 1275° to 2100°F. Only natural sea water was used as a diluent.

III. CONCLUSIONS AND RECOMMENDATIONS

A. The type of performance desired for the external-condensing hydroductor is shown by the tests made on Model X3. The performance of this model appears to be satisfactory for certain operating conditions; the data indicate that lengthening of the afterbody might make the performance more uniform over a wider range of operating conditions. It is recommended that tests on the external-condensing hydroductor models continue on the rotating boom. The shape of the afterbody should be determined for most uniform performance at varying depths. Correlation of the model performance data with the performance necessary for a free-running test vehicle should continue.

B. On the basis of the results of the study program on the power plant for a small high-speed submarine, it was concluded that it is feasible to design and develop a small chemical power plant for this application. This power plant should use 90% concentrated hydrogen peroxide and diesel fuel as the propellants with sea-water diluent. For best performance with varying depth of operation, a condensing system should be used that consists of a condenser on the turbine exhaust, a condensing water pump, and a "froth" compressor pump for discharge of the mixture of water and carbon dioxide. It is feasible to design this power plant so that it will be operationally convenient, simple, reliable, and entirely safe. It is recommended that further theoretical and experimental work be conducted on the reduction or elimination of noise for a power plant such as the one studied. In addition, it is recommended that development of such a power plant be initiated so that more complete performance data and specifications would be available for incorporation into the design of a small high-speed submarine.

C. Data from the sea-water diluent program during this reporting period indicated that the most satisfactory operation is still obtained by using a strong cationic-exchange treatment of the sea water. Further improvement can probably be obtained when a graphitic coating is applied to the internal surfaces of the combustion hardware and when the combustion chamber temperatures are kept relatively high. The required size of the cationic-exchange bed will be small enough for practical application in torpedoes. Further work is necessary to determine the method for obtaining the best yield of the bed. The additional tests with sea water containing additives, made in an attempt to change the nature of the solid deposits, were not as promising as those using the cationic-exchange or hardware coating techniques. The use of colloidal clay and "chelating" agents were included in the group of additives which were investigated during this period. A few tests were made to obtain more detailed information on the effect of various combustion temperatures on the solid deposits; further work is necessary along this line to prove that turbine operation will be satisfactory. The use of certain electrolytic treatments of the sea water should be studied in view of successes reported for certain commercial applications with hard water. Additional long-duration tests should be made on the most promising system or combination. These tests should be made with the gas generator only, and with the complete turbine system at various simulated depths. The entire program should continue to include tests with 70% E H_2O_2 and alcohol as well as with 90% H_2O_2 and diesel fuel.

IV. HYDRODUCTOR

A. PROGRAM PLAN

1. Previous development work on the hydroductor motor has been reported in References 2 and 3. The operational advantages to be gained from an underwater missile capable of high velocities, and whose performance is relatively insensitive to depth, are realized to be important enough to justify continued development of the hydroductor. The study and testing of the external-condensing hydroductor configuration has been emphasized during the present program because such work promises to provide a more rapid solution to the design of the free-running hydroductor test vehicle.

2. A schematic diagram of the external-condensing hydroductor is shown in Figure 1. The internal configuration of this motor is identical with that of the hydroduct. Through proper design of the steam nozzles and afterbody of the missile, depth-insensitivity can be expected without a serious increase in total drag. Under shallow-water operating conditions, the motor would run as a hydroduct. When the ambient back pressure increases due to greater operating depth, the steam cavity would be made shorter because of the increased pressure. The flow pattern would change under these conditions, so that some of this pressure could be recovered on the afterbody of the missile; reduced drag would result. Therefore, the present program is to determine the most

favorable configuration of the steam nozzle and afterbody section of the external-condensing hydroductor.

B. TEST PROGRAM

1. Drag Tests

a. The first step in the testing program was to determine whether there is significantly less drag for any particular afterbody shape. In addition to a completely faired afterbody (for reference purposes), the tail-section shapes shown in Figure 2 were tested. The basic model used for the drag tests was the 3.25-in.-dia test model (Figure 3) used in several previous programs. This model is attached to a hollow strut through which steam can be delivered to the model. For the drag tests, the tail section of the model was replaced by sections of the experimental shapes without steam nozzles. The special test-model tail sections were cylindrical and so designed that the total skin area, exclusive of the base area, was the same as that of the completely faired tail section. The model and strut were mounted on the extension arm of the rotating boom at the 50-ft radius. Drag measurements were obtained at velocities up to 158 ft/sec. Two complete sets of drag measurements were obtained for each model tested.

b. The drag curves obtained from the tests of Model A, Model C, (see Figure 2) and the faired afterbody are shown in Figure 4. The drag values shown are the gross values obtained, which include the drag of the model and the strut, since it was desired to determine the differences in the drag values of the various afterbody shapes. Figure 5 shows the difference between the drag of Model A, Model D, and the faired afterbody. Drag tests of afterbody shapes B and E (see Figure 2) were also made on the rotating boom in the ring channel and the drag curves obtained were very similar to those obtained on Models C and D. Microflash photographs made during these drag tests are shown in Figures 6, 7, 8, and 9. The data from all of these tests did not show any striking evidence that one afterbody shape would be more feasible than another for use with the external-condensing hydroductor. It was hence concluded that model tests, using steam, would have to be conducted to furnish the desired information.

2. Performance Tests with Steam

a. Using the rotating boom, performance tests were made of several external-condensing hydroductor models. The nozzle block configuration for each model is shown schematically in Figure 10. Each block has 20 small nozzles in an annular ring. The combined throat area of these nozzles is 0.50 in.^{2}, the same as that of the hydroduct model (Figure 3) used for previous tests and presently available for comparison of performance. To obtain comparative performance data, steam was supplied from the accumulator on the rotating boom through a hollow strut to the model. Different operating conditions were simulated by making tests at various velocities and by also varying the maximum steam pressure available from the accumulator. The test data, which included gross drag of the model and strut, steam pressure (P_c) in the model just forward of the nozzles, rotating boom speed, and the various pressures on the afterbody or nozzle block, were recorded on an oscillograph tape. Microflash photographs were also taken of some of the models at various operating conditions to correlate pictures of the external flow with the performance data.

b. Initial tests were made of external-condensing hydroductor Models X3, X4, and X5 to determine if there were marked differences in their performance. For these tests, only a single pressure point was used, at the end of the afterbody or at the center of the nozzle block. Figure 11 shows the data obtained on one of the test runs of Model X3. The numbers at the top of this performance curve indicate the time during the run when microflash photographs were taken of the model. Some of these photographs are shown in Figures 12, 13, 14, and 15. During the initial phase of this test, when steam pressure is relatively high, the motor is running in a manner similar to a hydroduct. During the middle phase of the test run, at an elapsed time of 23 sec, the steam pressure in the chamber has been reduced considerably but there is an appreciable increase in the net thrust of the motor, as shown by the large dip in the drag curve. The external flow of condensed steam and water is collapsing on the afterbody, as shown by the increase in rear-stagnation pressure (also see microflash photograph No. 6 - Figure 15). These are the effects that are being investigated in this part of the program.

c. A performance curve for Model X4 is shown in Figure 16. Microflash photographs were taken during this test at the time intervals shown by the numbers at the top of the performance curves. Some of these photographs are shown in Figures 17, 18, and 19. A single pressure tap was drilled in the center of the nozzle block. The effect of reduced drag, because of collapse of the flow on the rear of the model, was not appreciably evident in this test. The pressure on the center of the nozzle block, inside the annular ring of the nozzles, increased while steam was flowing but did not attain significantly positive values as did that of Model X3. Model X4 was altered by machining the button from the center of the nozzle block as shown in Figure 20. Performance data on this model (X5) were very similar to the data obtained on Model X4.

d. As the performance of the Model X3 appeared to benefit from the closing of the external flow under certain operating conditions, additional tests were made of this unit. Four more pressure taps were drilled in the afterbody at the points shown in Figures 21 and 22. Data obtained from these tests made at various velocity and steam-pressure conditions are shown on the curves of Figures 23 through 28. The cavitation parameter (σ_k) was calculated for the minimum pressure of the cavity as recorded from pressure taps No. 3 and 4. The cavitation parameter is defined as

$$\sigma_k = \frac{P_\infty - P_k}{1/2\ \rho\ V_\infty^2}$$

where

P_∞ = pressure in undisturbed fluid

P_k = pressure in open cavity regardless of the gas with which cavity is filled

ρ = density of liquid

V_∞ = velocity of undisturbed flow

e. From the Model X3 test data, calculations were made of the thrust coefficient, C_F, at various values of chamber pressure. To obtain the net thrust value to use in the calculation of the thrust coefficient

($C_F = F/P_c A_t$), it was first necessary to determine the basic drag curve of the model. This curve is Figure 29. The values used to plot the curve were obtained from the various tests and then corrected to account for the difference in drag before the steam was turned on and during the actual test run. The correction was figured as a suction drag on the model and was calculated by multiplying the pressure reading at pressure tap No. 5 (just aft of the exit plane of the nozzles) by the area of the exit section of the nozzles. This value was then subtracted from the drag reading at time zero (before the steam was turned on) to give a more realistic value of the drag during operating conditions. The difference between this basic drag reading and the drag reading at various times during the test was taken as the net thrust of the unit. The calculated values of C_F were plotted on the performance data curves of Figures 23 through 28.

C. DISCUSSION

1. Data from the lower-velocity tests of Model X3, such as those shown in Figures 26, 27, and 28, indicate that the afterbody shape of this model is more suitable for these velocities. At these values of the cavitation parameter, the cavity is closing on the afterbody when the chamber pressure is near the maximum and the effect is similar to an increase in thrust. To obtain comparable performance at higher velocities, the afterbody should be longer. Another model (designated X7) is being designed to use the same nozzle block as Model X3, but the afterbody will be approximately twice as long.

2. Data were obtained from the Model X3 tests under conditions that yield a range of cavitation numbers from .052 to .476. These conditions simulate the operation of a free-running model at a velocity of 190 ft/sec and variation in the operating depth from 10 to 250 ft. The thrust coefficient values, obtained under the test conditions which produced the higher cavitation numbers (Figures 27 and 28), appear to be adequate. These values indicate that a free-running test vehicle, designed to be similar to the Model X3 hydroductor, should have satisfactory performance at operating conditions that would yield the same cavitation number but that performance might be marginal at the very low cavitation numbers. It is anticipated that the performance of one of the external-condensing hydroductor models with a longer afterbody will be more uniform throughout the range of desired operating conditions.

V. SUBMARINE POWER PLANT FEASIBILITY STUDY PROGRAM

A. The detailed results of the power plant study for a small, high-speed submarine are presented in Reference 1.

B. On the basis of the investigations conducted during this program, the following general characteristics and features of a 1900 shp power plant system represent the best design from a standpoint of performance, size and basic simplicity:

1. The propellant tanks are of Dacron and Mylar exposed to the ambient sea-water pressure.

2. The propellants used are 90% H_2O_2, diesel fuel, and sea-water diluent.

3. The turbine wheel is of 12-in. dia with a rotative speed of 25,000 rpm and operating temperature of 1900°F.

4. A condensing system is used on the turbine exhaust with a vane type compressor pump to discharge the water-CO_2 mixture from the condenser to the ambient sea water.

5. Special sliding-ring variable displacement-positive displacement vane pumps are used for all propellants to simplify the power-plant control system.

6. A 5-hp combination electric motor and generator is used to provide for low-speed operation, reversing, and starting of the main power plant and auxiliary diesel engine.

7. The power-plant performance is 6.29 and 7.04 lb of expendibles per shaft horsepower hour for operation at the surface and at 1000 ft depth, respectively.

8. A planetary reduction gear system is used with the turbine.

9. The combustion chamber is of the "bluff body" type.

C. The primary advantages gained from the above design with a condensing system compared to designs without a condensing system are listed below:

1. A high efficiency turbine performance is obtained at depth.

2. Only a single decomposition and combustion chamber assembly is required.

3. The combustion pressure is lower at depth and less power is required for the propellant pumps.

4. The flushing action is improved for the sea-water solids in the turbine exhaust.

5. The power plant size is smaller (3 ft OD by 3 ft).

D. The disadvantages in using the above condensing system include a slight increase in weight and complexity of the complete power plant with the addition of the condensing system equipment.

VI. SEA-WATER DILUENT PROGRAM

A. BACKGROUND

One of the best chemical power-plant systems at present uses hydrogen peroxide and a hydrocarbon fuel. While such a plant is relatively efficient, of primary importance is the fact that it is essentially wakeless. However, because the reaction temperatures of hydrogen peroxide and a hydrocarbon fuel are excessive for turbine operation, diluent water must be added to cool the gases to a reasonable temperature, in order to prevent erosion or over-stressing of the turbine blades. Fresh water is normally carried by the vehicle for this purpose, but the considerable space occupied by fresh-water tanks could be available for additional propellant if ambient sea water were used as the diluent. The use of sea water as a diluent for hydrogen-peroxide engines has been investigated by several agencies, but completely satisfactory performance has not been obtained.

B. PROGRAM PLAN

This program was planned to supplement previous efforts and to investigate other techniques for obtaining satisfactory use of sea water as a diluent. A range of operating temperatures from 1275 through 2100°F was investigated using 90% H_2O_2 with diesel fuel or 70% E H_2O_2 with 92.5% ethyl alcohol. The studies were made on the designs and systems which would be most applicable for use in high-performance torpedo power plants. The work performed at a time previous to this report period is described in Reference 2. The investigation, continued during this reporting period, was primarily concerned with:

1. Cationic-Exchange Treatment of Sea Water

a. Improvement of the bed design for the Amberlite IR-120 exchange resin.

b. Determination of the sea-water flow system for a minimum size cationic exchange bed.

2. Chemical Additives

Tests were carried out using chemical and other additives to the sea water or fuel in order to change the nature of the solids formed, with the objective that deposits will not occur or can be readily flushed away. Colloidal materials and "chelating" agents were investigated.

C. METHOD OF TEST

1. The thrust-dynamometer installation used included devices to simulate solid deposit conditions on turbine blades and in a turbine exhaust system with a gas generator utilizing hydrogen peroxide and fuel. A Mk 16-6 torpedo energy section and a new combustion chamber of an experimental design (see Figures 1, 2, and 3 of Reference 2) developed under Contract NOrd 16510 were used for all the tests conducted with 70% E H_2O_2 and 92.5% ethyl alcohol. For the tests made with 90% H_2O_2 and diesel fuel, this combustion chamber was slightly modified by changing the liner and enzian ring components to decrease the size of the cooling water passages and thus increase the velocity of the cooling water. Although the main objective of the program is to determine the best method for utilizing ambient sea water with a combustion system employing 90% concentrated hydrogen peroxide and diesel fuel, it was realized that very pertinent and important information concerning the use of sea-water ion exchange

and additive techniques could be obtained by using lower-strength peroxide and alcohol as energy sources for some of the work during the course of the program. Furthermore, such propellant was on hand, together with certain vitally needed torpedo components and workshop gear (through the cooperation of the Bureau of Ordnance) and its use has resulted in a considerable saving of time and money for this program.

2. Special cartridge units were installed in the sea-water line on the dynamometer installation for some of the tests (see Figures 30, 31, and 32). The cartridge units contained various sizes and shapes of beds using Amberlite IR-120 exchange resin for processing the sea water prior to injection into the combustion chamber. Tests were also performed using only the cartridge units and measurements were made of the percentage of cationic exchange as a function of time at various sea-water flow rates.

3. A special adapter containing a steel bar and two steel collector screens was placed downstream of the gas generator nozzle to simulate the turbine blades and the turbine exhaust system. Following each test run, the deposits of sea-water salts in the combustion chamber and collector system were photographed, weighed, and chemically analyzed. Photographs of the complete thrust dynamometer are shown in Figures 31 and 32. Figure 30 presents the thrust dynamometer installation less the exhaust collector system. The three propellant flow meters (orifice-d/p cell type) are shown on the side of the thrust stand in Figures 30 and 31. (The Annin valves on the meter lines are not used for this program; flows are controlled with orifice restrictions or with Waterman-type constant delivery valves.) The stainless steel sea-water diluent tank is visible at the left side of Figure 30 against the wall of the test pit. A small portion of the diesel fuel tank is visible above the dynamometer (left of center) in Figure 31. The Mk 16-6 torpedo air flask and the peroxide and fuel tanks are located inside the steel box at the right of Figures 30, 31, and 32.

4. The runs with additives were made without the use of the cationic exchange units. The various chemicals were simply added to the sea water for these tests.

D. RESULTS OF TESTS

1. Natural sea water was used for all tests throughout this report period. The sea water was obtained offshore from the U.S. Naval Ammunition and Net Depot, Seal Beach, California. A chemical analysis of all the sea water samples that have been used is presented in Table 1. The sample of sea water used for each test is identified in Tables 2 and 3.

2. A brief description and results of all tests conducted with the peroxide combustion systems are shown in Tables 2 and 3. The data regarding the total weight of solids deposited in the combustion chamber and exhaust system are presented in Tables 4 and 5. Brief discussions of some of the tests, together with the tests involving only the cationic exchange units, are covered in the paragraphs below.

a. Tests No. 17 and 25 are the reference runs (without any diluent treatment) for the tests made with 70% E H_2O_2 and 92.5% ethyl alcohol and the two different samples of natural sea water. The solids deposited in the combustion chamber for these runs are shown in Figures 33 and 34 while the solids deposited on the exhaust collector screens are shown in Figures 35 and 36. The results of run No. 25 indicated a similar quantity, but slightly larger quantity of solid deposits than were obtained in run No. 17. This larger quantity can probably be attributed to the lower combustion chamber temperature (1275°F for run No. 25 vs 1550°F for run No. 17) and the slight difference in sodium concentration between the two sea-water samples.

b. Several tests were made using different sizes and configurations for the cationic exchange cartridge. The data from test No. 21, 22, 24, and 26 should be compared with the two reference tests (No. 17 and No. 25). There was a very significant reduction in the solid deposits for run No. 22 when the cationic exchange bed was increased in size to 12.5-in. dia x 5.5-in. Figure 37 shows the solids deposited in the combustion chamber for run No. 22 and Figure 38 shows the solids deposited on the exhaust collector screens.

While there was decided improvement in results when the run duration was limited to 2 min, the results for run No. 26 showed that the 12.5-in. dia x 5.5-in. cationic exchange cartridge was not adequate for the longer duration runs.

c. Tests No. 19 (reference), 20, and 23 were made with 90% H_2O_2 and diesel fuel. The data from test No. 20 shows that the 6-in. dia x 6-in. cationic exchange bed was too small because there was no significant reduction in the amount of solids deposited. When the larger size cartridge was used in run No. 23, a significant reduction in solid deposits was obtained. A photograph of the combustion chamber after run No. 19 is shown in Figure 39 and Figure 40 shows the combustion chamber after run No. 23.

d. A measure of the effect of chamber temperature on the solids deposited is shown by comparing tests No. 17 and 19. The total weight of solids into the system is greater for run No. 19 than for run No. 17, yet the amount deposited is less. Chamber temperatures were 1550°F for No. 17 and 1950°F for No. 19 (also see Figures 33 and 39).

e. Five tests (not numbered) were made to determine the output efficiency of the strong cationic exchange beds used for some of the combustion tests described above, and of new bed designs for subsequent combustion tests. For these investigations, samples were taken at specified time intervals from the processed sea water being discharged from each bed. The percentage [illegible] exchange was determined for each sample and this value was taken as the percentage of cationic exchange.

The first test was conducted on the 6-in. OD by 6-in. bed used for run No. 20. The percentage of sodium exchange was determined to be 85% at 10 sec and 26% at 120 sec from the start of the run.

f. Three tests were made with natural sea water flowing through resin beds of two different sizes. The beds of strong cationic exchange resin, Amberlite IR-120, were 12.5-in. OD with lengths of 2.0 in. and 5.5-in. (see Figure 31). The run durations were 2.0 min, corresponding to the usual test run; and 15 min, corresponding to a maximum torpedo running time. The results of these tests are shown on the curves of Figures 41 and 42.

g. An analysis of all the test results with the different sizes of strong cationic exchange beds revealed that the percentage of ion exchange at the start of each run should be decreased and the percentage of ion exchange at the end of each run should be increased (essentially "flattening" the output curve of the bed) to obtain the maximum effectiveness from any given size bed for this application. To "flatten" the output curve of the cationic exchange bed, special designs of the bed component were investigated as well as arrangements for bypassing a portion of the sea-water flow around the bed.

h. An ion exchange test was made to investigate the output characteristics of the 12.5 in. OD by 5.5 in. bed with a sea-water flow rate of 11.5 lb/min (approximately half the normal flow rate). The results are presented in Figure 43.

i. A flow test was made with a strong cationic exchange bed of 3 in. di[illegible] by [illegible] ft (made by connecting two 4-ft chambers in series). This [illegible] Figure [illegible] 120 exchange resin used was the same as that u[illegible]ous ion exchange [illegible] bed si[illegible] of 12-1/2-in. OD by 5.5 in.). A constant flow of sea water at 23 lb/[illegible] maintained through the bed during the test. The percentage of cationic exchange was measured as a function of time for a 9-min period (see Figure 44). The purpose of the test was to determine if a more desirable characteristic of percent ion exchange vs time could be obtained with a higher length-to-diameter ratio for bed shape. Results indicated that there was no significant improvement.

j. Another flow test was made using the above ion-exchange unit (Figure 32) but with 50% of the sea water bypassed around the bed during the first half of the test period (see Figure 44). The results using this method were encouraging and further tests are planned to vary the percentage of the sea water bypassed around the bed during the entire test period. On the basis of the foregoing test results, it is believed that if the percentage of cationic exchange can be maintained above a minimum value of approximately 40%, the amount of solid deposits will be kept to satisfactory level for operation of the torpedo engine.

k. Six tests were conducted with special additives in the sea-water diluent. These additives were of two general categories: chelating agents and colloidal materials. These six tests (No. 27 through 32) are described and results presented in Tables 3 and 5.

Tests No. 27 and 28 were made with Quebracho, which is used with boiler feed water in some commercial applications. Tests No. 29 and 30 used a detergent, Tergitol Anionic 08, which has been investigated to some extent by USNOTS, Pasadena, for use in combustion tests with fluidized metals, peroxide, and diluent sea water. Difficulty was experienced with the burning of hardware surrounding the primary (hot) combustion zone on runs No. 29 and 30. This damage was due to the poor heat-transfer characteristics of the diluent in the regenerative cooling passages as a result of the foam formed in the sea water by the Tergitol additive. Runs No. 31 and 32 were made using lignin extract and hydrazine sulfate additives, respectively. The overall results with these additives were not encouraging.

REFERENCES

1. Feasibility Study: Power Plant for a Small High-Speed Submarine, Aerojet-General Corporation Report No. 1259, 12 June 1957 (Confidential).

2. Underwater Propulsion Devices, Aerojet-General Corporation Report No. 1238, 14 March 1957 (Confidential).

3. Research, Development, and Testing of Underwater Propulsion Devices, Aerojet-General Corporation Report No. 1106, Volumes I and II, 31 May 1956 (Confidential).

TABLE 1

COMPOSITION OF SEA-WATER DILUENT SAMPLES

Constituent	Synthetic Sea Water (Diluent E) % by wt	Harbor Sea Water (Diluent F) % by wt	Offshore Sea Water (Diluent G) % by wt	Harbor-Entrance Sea Water (Diluent H) % by wt
H_2O	96.57	96.52	96.56	96.41
Salts	3.43	3.48	3.44	3.59
Sodium	27.0	25.0	29.58	33.0
Magnesium	4.1	4.9	3.5	3.4
Calcium	3.8	4.2	4.1	2.7
Aluminum	0.0028	0.0038	0.001	0.0012
Silicon	0.039	0.063	0.032	0.049
Potassium	3.2	3.1	3.1	2.2
Strontium	0.11	0.063	0.052	not reported
Chromium	trace	0.00047	0.017	0.0073
Iron	0.033	0.016	0.12	0.013
Boron	0.080	0.072	0.036	0.048
Copper	0.0024	0.00048	0.0011	0.00076
Nickel	not reported	not reported	0.0038	0.0016
Manganese	not reported	not reported	0.0014	0.00082
Titanium	not reported	not reported	nil	0.0060

TABLE 2

DESCRIPTION OF TESTS, ONR SEA-WATER-DILUENT PROGRAMS

6/6/56 to 12/5/56

Run No.	Fuel[1] and Flow Rate lb/min	Oxidizer[2] and Flow Rate lb/min	Diluent[3] and Flow Rate lb/min	Diluent Additive	Average Combustion Temperature F	Decationized Amount of Diluent %	Remarks
1	A - 8.05	C - 46.0	E - 25.0	None	--	None	Reference run. Considerable deposit of salts in chamber and on collectors. Run duration 3 min.[4]
2	A - 10.4	C - 42.5	E - 25.1	None	1340	36.8	Sea water acidic from ion exchange process. Salt deposits 20% of Run No. 1.
3	A - 10.3	C - 44.8	E - 24.4	None	1580	50.0	Results similar to Run No. 2.
4	A - 9.9	C - 44.7	E - 22.2	HCl	1578	None	Considerable deposits of salts in chamber and on collectors. Less than Run No. 1, however.
5	A - 10.9	C - 43.7	E - 18.9	$ZnCl_2$	1670	None	Additive increased amount of solids produced but did not satisfactorily decrease amount of solids deposited.
6	A - 9.9	C - 40.8	E - 18.3	None	1620	None	Graphite and varnish applied to internal surface of combustion chamber and exhaust system. Materially less deposits of salts than Run No. 1.
7	A - 10.1	C - 41.3	E - 21.5	$FeCl_3$	--	None	Reaction products appeared to form oxides and considerable deposit of solids in system.
8	A - 9.8	C - 40.4	F - 23.6	None	--	None	Slightly more solid deposits than Run No. 1 but of a soft, putty-like composition.
9	A - 11.0	C - 41.4	F - 22.0	NaOH	1330	None	More solid deposit in exhaust system than Run No. 8, and of hard-crust composition.
10	B - 3.8	D - 32.8	F - 20.0	None	2340+	None	45-sec duration run. Collector system not used so that exhaust could be observed. Diluent flow rate lower than desired. Bluff-body flame holder and injector requires slight modification for this fuel and oxidizer.
11	A - 9.5	C - 42.7	E - 20.0	NaOH	1490	None	Results comparable to Run No. 9.
12	A - 9.7	C - 41.0	E - 18.9	KOH	1300	None	Results slightly better than Run No. 11.
13	A - 9.4	C - 39.0	G - 21.7	None	1550	None	Reference run. Solid deposits of similar appearance to Run No. 1 but of less magnitude than both Runs No. 1 and 8.
14	B - 2.9	D - 29.2	G - 22.4	None	2000	None	Fuel leak invalidated run for use as reference.
15	B - 4.2	D - 31.6	G - 21.9	None	2000+	None	Run cut short because of malfunction of diluent control valve.
16	A - 5.5	C - 29.7	G - 22.5	None	1100	None	Slightly less deposit of solids in combustion chamber and more deposit in exhaust system than Run No. 13.

NOTES: (1) Fuel "A" is 92.5% ethyl alcohol.
Fuel "B" is diesel oil.

(2) Oxidizer "C" is 70% E concentrated hydrogen peroxide.
Oxidizer "D" is 90% concentrated hydrogen peroxide.

(3) Diluent "E" is synthetic sea water.
Diluent "F" is natural sea water obtained from the harbor at Seal Beach, California.
Diluent "G" is natural sea water obtained 2 miles offshore from Seal Beach, California.

(4) All runs were of 2 min duration unless otherwise noted.

TABLE 3

DESCRIPTION OF TESTS, ONR SEA-WATER DILUENT PROGRAM
6 December 1956 to 5 June 1957

Run No.	Fuel[1] and Flow Rate lb/min	Oxidizer[2] and Flow Rate lb/min	Diluent[3] and Flow Rate lb/min	Diluent Additive	Average Combustion Temp °F	Remarks[4]
17	A-8.45	C-40.0	G-23.4	None	1550	Reference run. Deposits smaller and more dense than with previous diluents.
18	A-	C-	G-	None	2100	Stoichiometric mixture ratio desired. Mixture ratio control failed. Invalid as reference.
19	B-4.27	D-35.1	G-32.8	None	1950	Reference run. Deposits smaller and more dense than lower temp, 70% H_2O_2-alcohol reference runs.
20	B-4.35	D-39.0	G-35.0	None	1965	Diluent water through exchange bed 6 in. dia x 6 in. No improvement over reference run No. 19.
21	A-9.73	C-43.0	G-20.4	None	1530	Diluent water through exchange bed 12.5 in. dia x 2 in. Slight improvement over reference run No. 17.
22	A-10.3	C-45.4	G-22.5	None	1400	Diluent water through exchange bed 12.5 in. dia x 5.5 in. Significant reduction in deposits from Runs 17 and 21.

Sheet 1 of 3
Table 3

TABLE 3 (cont.)

Run No.	Fuel[1] and Flow Rate lb/min	Oxidizer[2] and Flow Rate lb/min	Diluent[3] and Flow Rate lb/min	Diluent Additive	Average Combustion Temp °F	Remarks[4]
23	B-4.85	D-34.8	G-34.9	None	1850	Diluent water through exchange bed 12.5 in. dia x 5.5 in. Significant reduction in deposits from tho. of Runs 19 and 20.
24	A-9.4	C-32.6	G-12.3	None	1350	Diluent water through exchange bed 12.5 in. dia x 5.5 in. Run time = 6 min. Propellan flow rate control failed. Reliable comparisons could not be made.
25	A-10.3	C-41.2	H-23.8	None	1275	Reference run. Hard, light weight crystalline deposits similar to original reference run with synthetic sea water.
26	A-10.1	C-44.7	H-25.7	None	1430	Diluent water through exchange bed 12.5 in. dia x 5.5 in. Run tim = 7.5 min. Insufficient ion exchange bed capaci
27	B-4.23	D-36.3	H-32.8	Quebracho	1920	No apparent improvement.
28	B-4.43	D-35.5	H-29.3	Quebracho	1950	No apparent improvement.
29	A-10.1	C-42.7	H-27.4	Tergitol Anionic 08	1400	No overall improvement

Sheet 2 of 3
Table 3

TABLE 3 (cont.)

Run No.	Fuel[1] and Flow Rate lb/min	Oxidizer[2] and Flow Rate lb/min	Diluent[3] and Flow Rate lb/min	Diluent Additive	Average Combustion Temp °F	Remarks[4]
30	B-4.42	D-33.3	H-33.4	Tergitol Anionic 08	1850	No improvement.
31	A-8.32	C-43.2	H-29.0	Lignin Extract	1575	No improvement.
32	A-8.2	C-45.4	H-26.8	Hydrazine Sulfate	1650	No improvement.

NOTES: (1) Fuel "A" is 92.5% ethyl alcohol.
Fuel "B" is diesel oil.
(2) Oxidizer "C" is 70% E concentrated hydrogen peroxide.
Oxidizer "D" is 90% concentrated hydrogen peroxide.
(3) Diluent "G" is natural sea water obtained two miles offshore from Seal Beach, California (also see Table 1).
Diluent "H" is natural sea water obtained at the harbor entrance to the U.S. Naval Ammunition and Net Depot, Seal Beach, California (also see Table 1).
(4) All runs were of 2-min duration unless otherwise noted.

TABLE 4

TEST DATA, ONR SEA-WATER DILUENT PROGRAM

6 June 1956 to 5 December 1956

Run No.	Description	Total Weight of Solids into System During 2-Min Running Time lb	Total Weight of Solids Deposited in 2-Min Running Time: Combustion Chamber, lb	Total Weight of Solids Deposited in 2-Min Running Time: Exhaust System,(1) lb	Ratio of Sodium to Calcium in Exhaust System Deposits,(1) lb
1	100% synthetic sea water (reference run)	1.62	0.254	0.127	13:1
2	36.8% decationized synthetic sea water and 63.2% untreated synthetic sea water	1.09	0.086	0.043	35:1
3	50% decationized synthetic sea water and 50% untreated synthetic sea water	0.84	0.069	0.051	12:1
4	Synthetic sea water with HCl added(2)	1.52	0.16	0.061	13:1
5	Synthetic sea water with $ZnCl_2$ added(3)	5.24	0.35	0.036	4:1
6	100% synthetic sea water; interiors of system coated with graphite	1.33	0.15	0.038	5:1
7	Synthetic sea water with $FeCl_3$ added(4)	5.83	0.25	0.15	6:1
8	100% natural sea water	1.62	0.27	0.19	15:1
9	Natural sea water with NaOH added(5)	5.06	0.17	0.40	240:1
11	Synthetic sea water with NaOH added(5)	4.48	0.15	0.32	17:1
12	Synthetic sea water with KOH added(6)	5.32	0.10	0.19	4:1
13	Offshore sea water	1.49	0.14	0.062	15:1

(See Sheet 2 for notes)

TABLE 4 (cont.)

Run No.	Description	Total Weight of Solids into System During 2-Min Running Time lb	Total Weight of Solids Deposited in 2-Min Running Time: Combustion Chamber, lb	Total Weight of Solids Deposited in 2-Min Running Time: Exhaust System,[1] lb	Ratio of Sodium to Calcium in Exhaust System Deposits,[1] lb
14	Offshore sea water, 90% H_2O_2, and diesel fuel	1.542	0.092	0.026	17:1
16	Offshore sea water, 70% E H_2O_2, and ethyl alcohol	1.548	0.11	0.089	14:1

NOTES:

(1) Water-soluble solids only.

(2) HCl added in such an amount that the acid-to-solids ratio was equal to that produced by the partial ion exchange of Run No. 3.

(3) $ZnCl_2$ added in such an amount as to produce a eutectic with the sea-water salts (taken as NaCl) having a melting temperature of 503°F - 58.5 mole% $ZnCl_2$.

(4) $FeCl_3$ added in such an amount as to produce a eutectic with the sea-water salts (taken as NaCl) having a melting temperature of 316°F - 54 mole% $FeCl_3$.

(5) NaOH added in such an amount as to produce a mixture with the sea-water salts (taken as NaCl) having a melting temperature of 680°F - 78 mole% NaOH.

(6) KOH added in such an amount as to produce a mixture with the sea-water salts for which the melting temperature is undetermined - 78 mole% KOH.

TABLE 5

TEST DATA, OUR SEA-WATER DILUENT PROGRAM

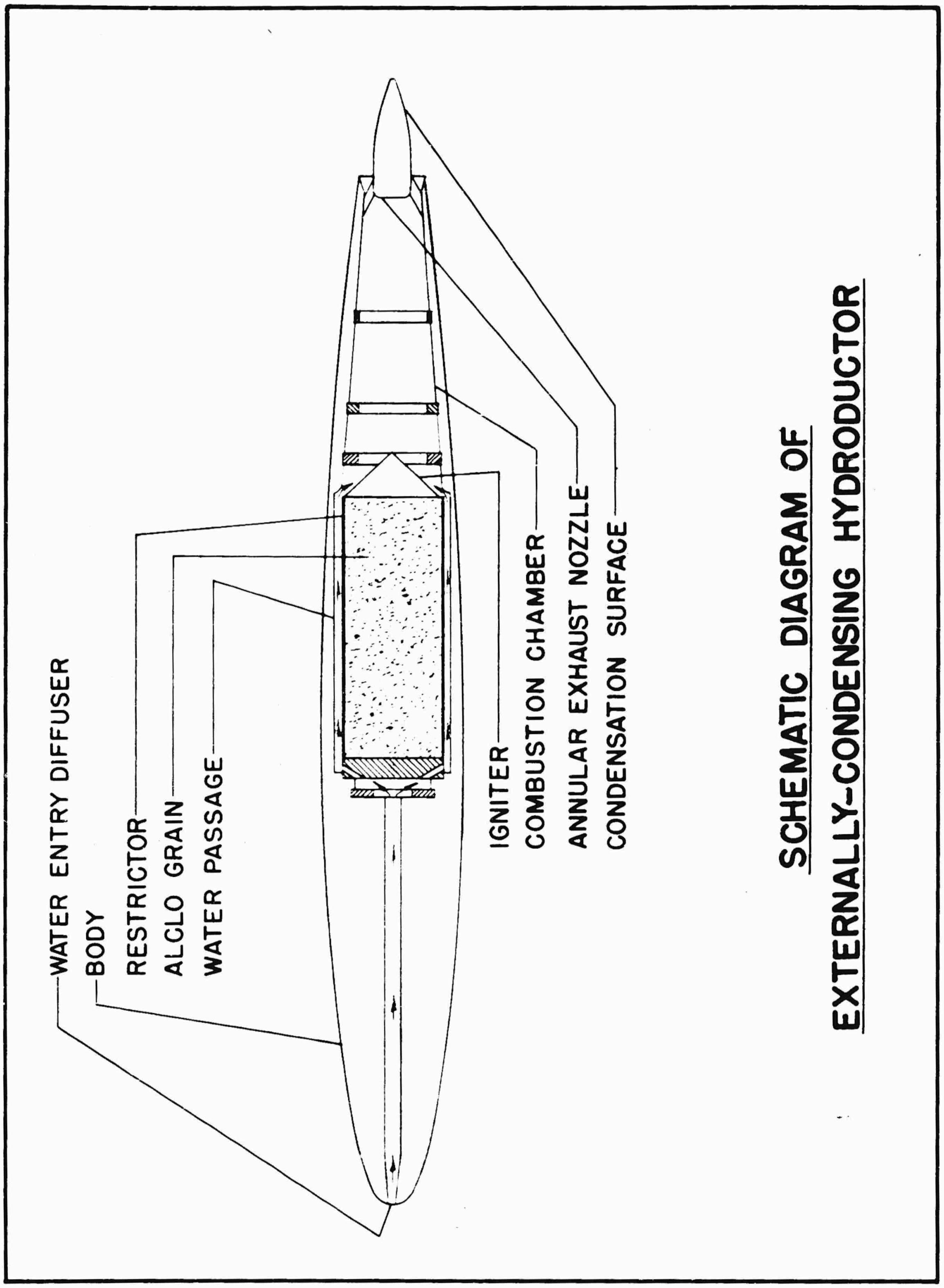
6 December 1956 to 5 June 1957

Run No.	Description (1)	Total Weight of Solids into System During 2-Min Running Time lb	Total Weight of Solids Deposited in 2-Min Running Time: Combustion Chamber, lb	Total Weight of Solids Deposited in 2-Min Running Time: Exhaust System, (2) lb	Ratio of Sodium to Calcium in Exhaust System Deposits, (2) lb
17	70% E H_2O_2-ethyl alcohol-sea water	1.61	0.15	0.044	11
18	70% E H_2O_2-ethyl alcohol-sea water	Data not valid			
19	90% H_2O_2-diesel fuel-sea water (Reference run)	2.26	0.065	0.072	10
20	90% H_2O_2-diesel fuel-sea water. Diluent water through 6 in. dia x 6 in. bed of strong cationic exchange resin	2.41	0.054	0.10	22
21	70% E H_2O_2-ethyl alcohol-sea water. Diluent water through 12.5 in. dia x 2 in. bed of strong cationic exchange resin	1.40	0.065	0.044	14
22	70% E H_2O_2-ethyl alcohol-sea water. Diluent water through 12.5 in. dia x 5.5 in. bed of strong cationic exchange resin	1.54	0.004	0.028	
23	90% H_2O_2-diesel fuel-sea water. Diluent water through 12.5 in. dia x 5.5 in. bed of strong cationic exchange resin	2.40	0.010	0.0056	
24	70% E H_2O_2-ethyl alcohol-sea water. Diluent water through 12.5 in. dia x 5.5 in. bed of strong cationic exchange resin (6-min run)	0.845 (av)	0.025 (av)	0.055 (av)	

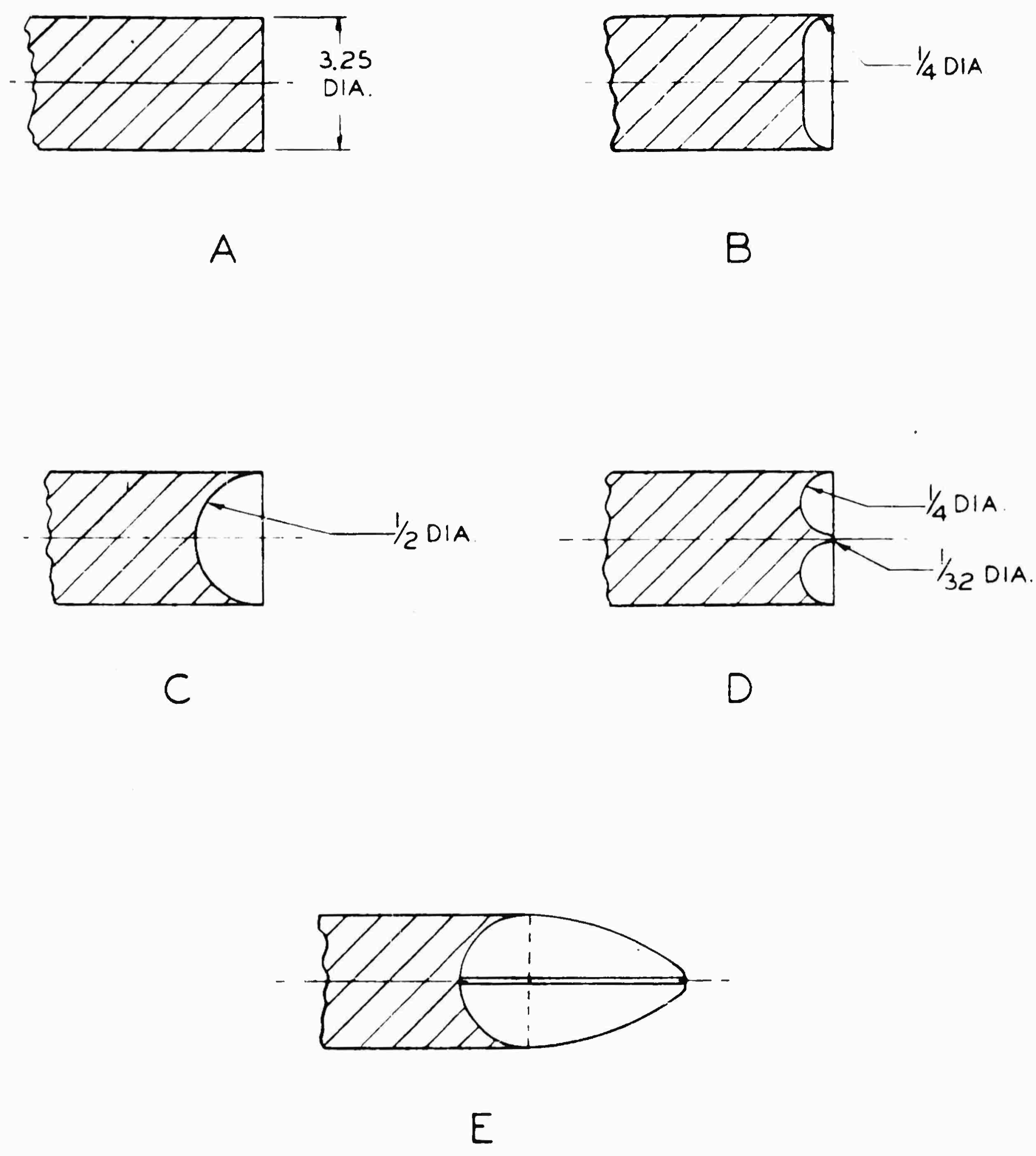
TABLE 5 (cont.)

Run No.	Description[1]	Total Weight of Solids into System During 2-Min Running Time lb	Total Weight of Solids Deposited in 2-Min Running Time: Combustion Chamber, lb	Total Weight of Solids Deposited in 2-Min Running Time: Exhaust System,[2] lb	Ratio of Sodium to Calcium in Exhaust System Deposits,[2] lb
25	70% E H_2O_2-ethyl alcohol-sea water (Reference run)	1.65	0.32	0.18	
26	70% E H_2O_2-ethyl alcohol-sea water. Diluent water through 12.5 in. dia x 5.5 in. bed of strong cationic exchange resin (7.5 min run)	1.76 (av)	0.115 (av)	0.27 (av)	46
27	90% H_2O_2-diesel fuel-sea water. 23 ppm Quebracho added to diluent	2.26	0.15	0.11	14
28	90% H_2O_2-diesel fuel-sea water. 1150 ppm Quebracho added to diluent	2.02	0.17	0.056	9
29	70% E H_2O_2-ethyl alcohol-sea water. 5.5% Tergitol Anionic 08 added to diluent	1.89	0.082	0.339	11
30	90% H_2O_2-diesel fuel-sea water. 5.3% Tergitol Anionic 08 added to diluent	2.30	0.17	0.18	25
31	70% E H_2O_2-ethyl alcohol-sea water. 0.116% Maracell E (lignin extract) added to diluent	2.00	0.19	0.26	22
32	70% E H_2O_2-ethyl alcohol-sea water. 0.1% hydrazine sulfate added to diluent	1.85	0.27	0.21	19

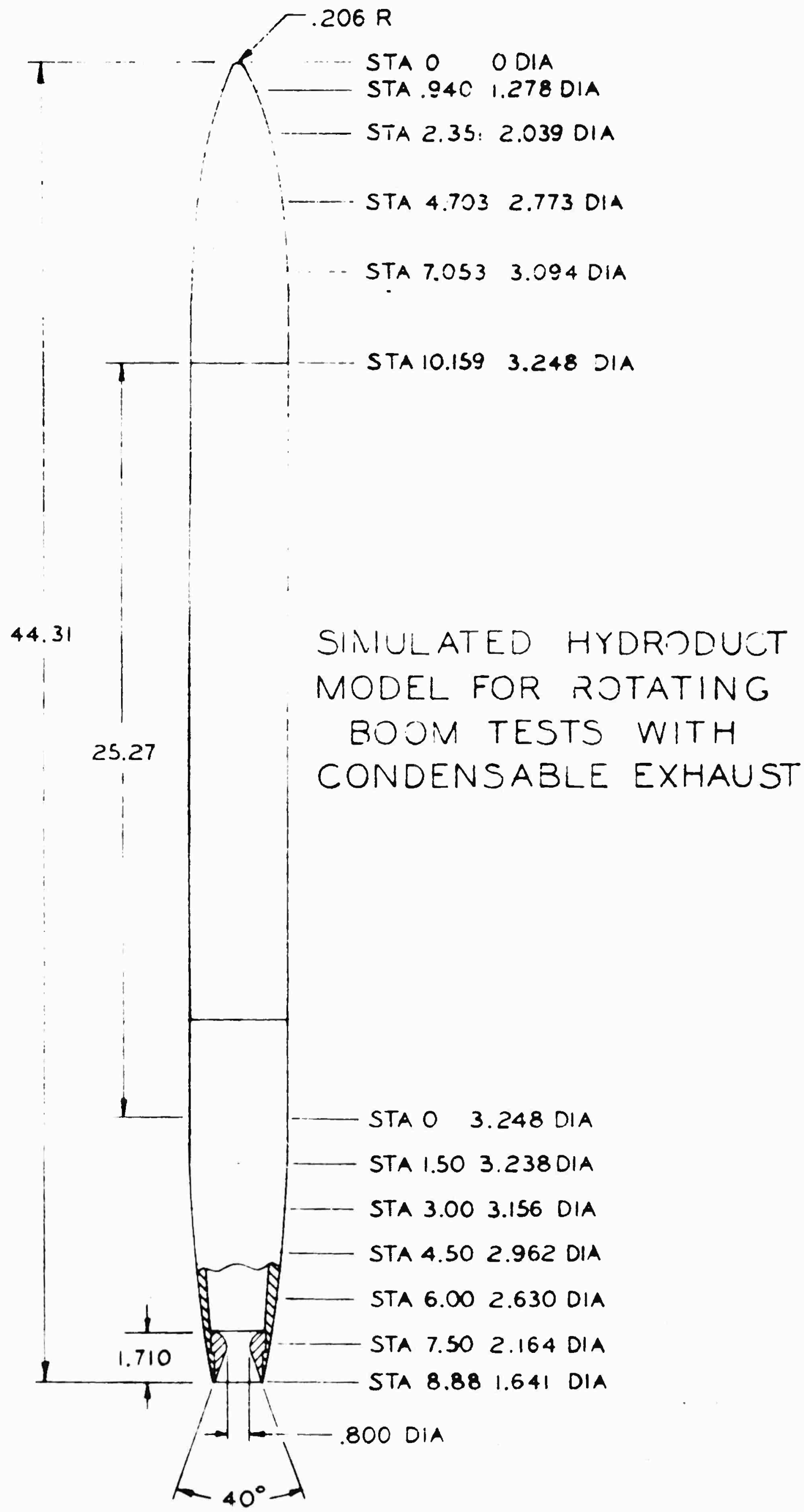
NOTE: (1) All runs were of 2-min duration unless otherwise noted.
(2) Water-soluble solids only.



SCHEMATIC DIAGRAM OF EXTERNALLY-CONDENSING HYDRODUCTOR



SPECIAL AFTERBODY SHAPES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44.31
25.27
SIMULATED HYDRODUCT
MODEL FOR ROTATING
BOOM TESTS WITH
CONDENSABLE EXHAUST
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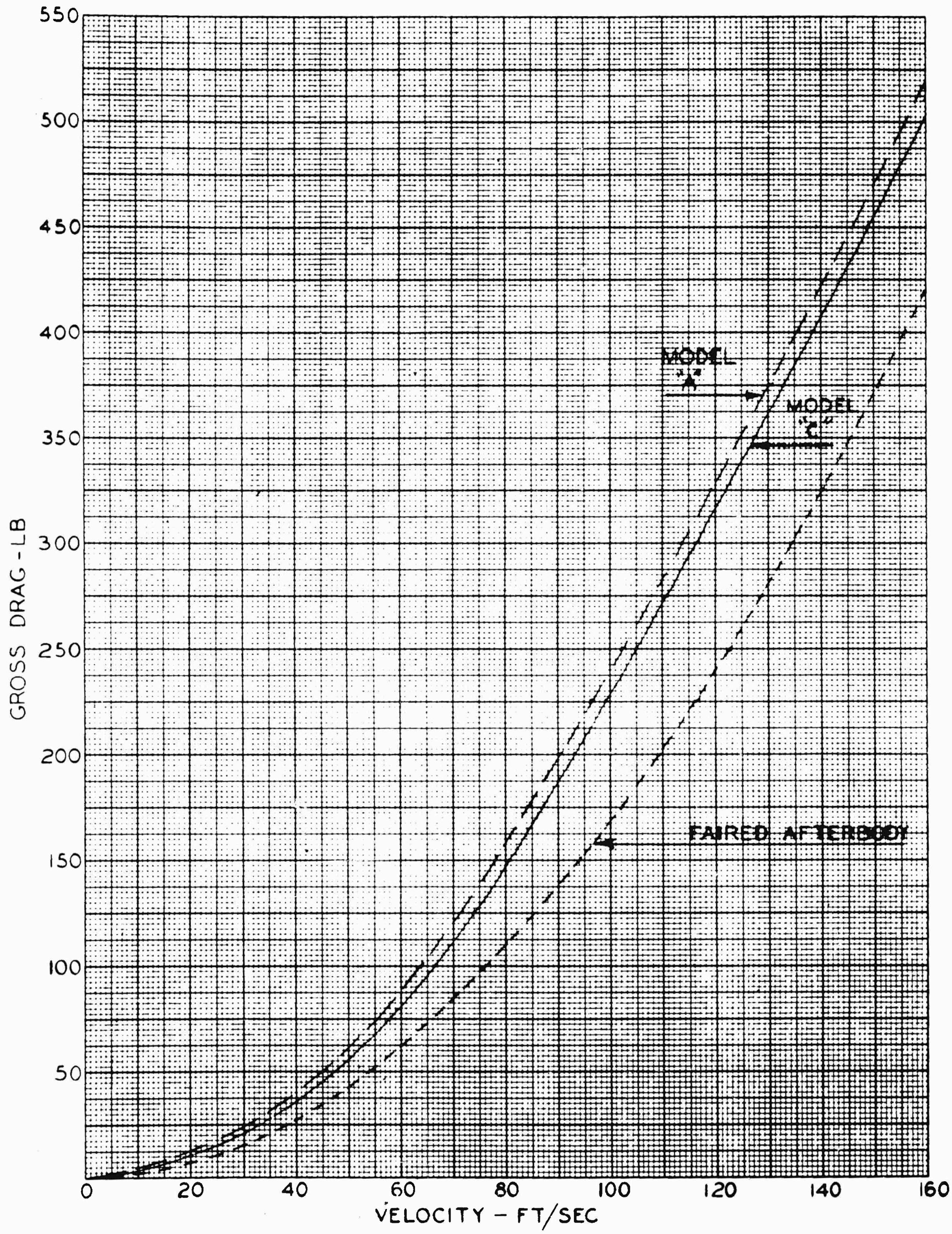
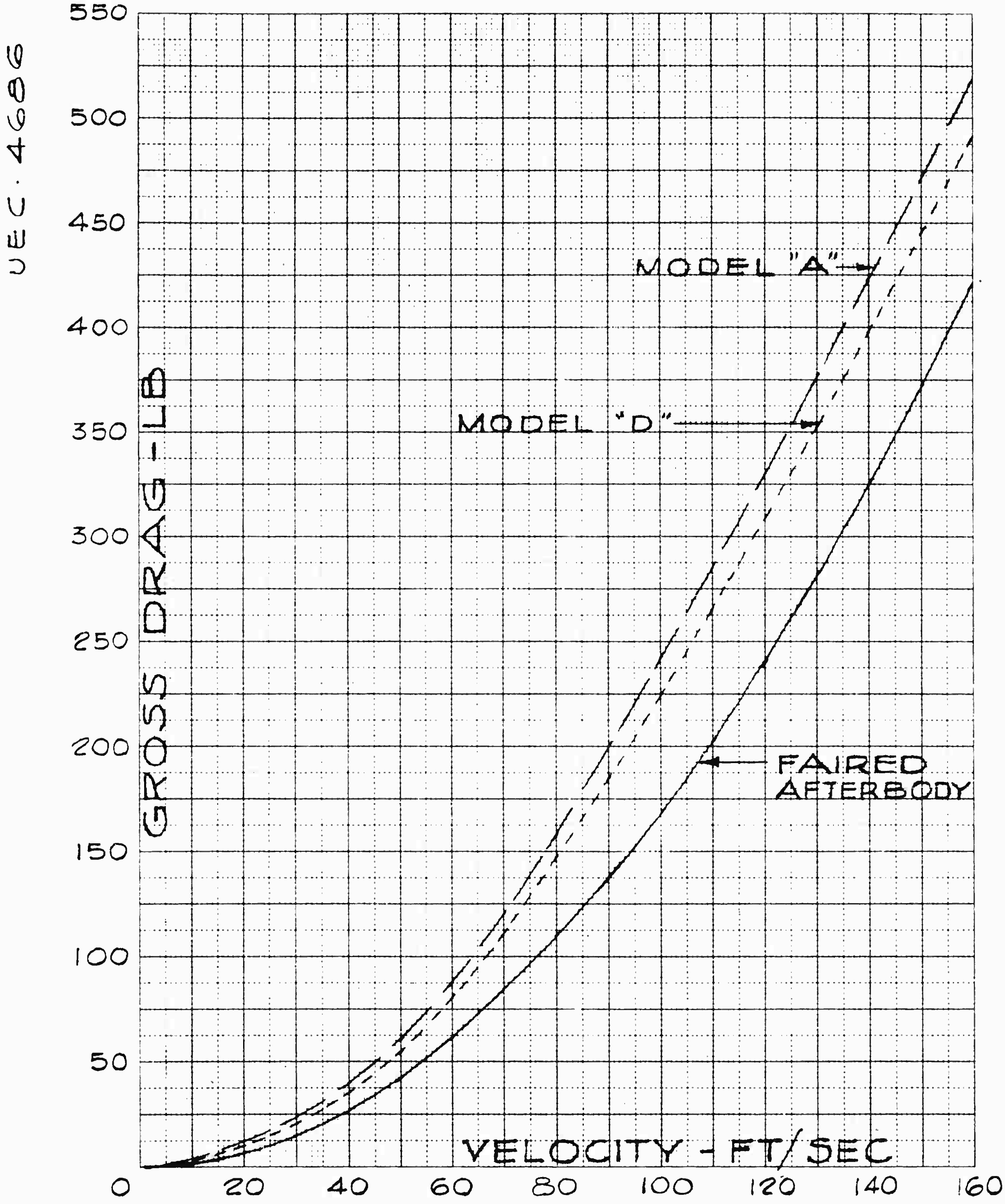


COMPARATIVE DRAG



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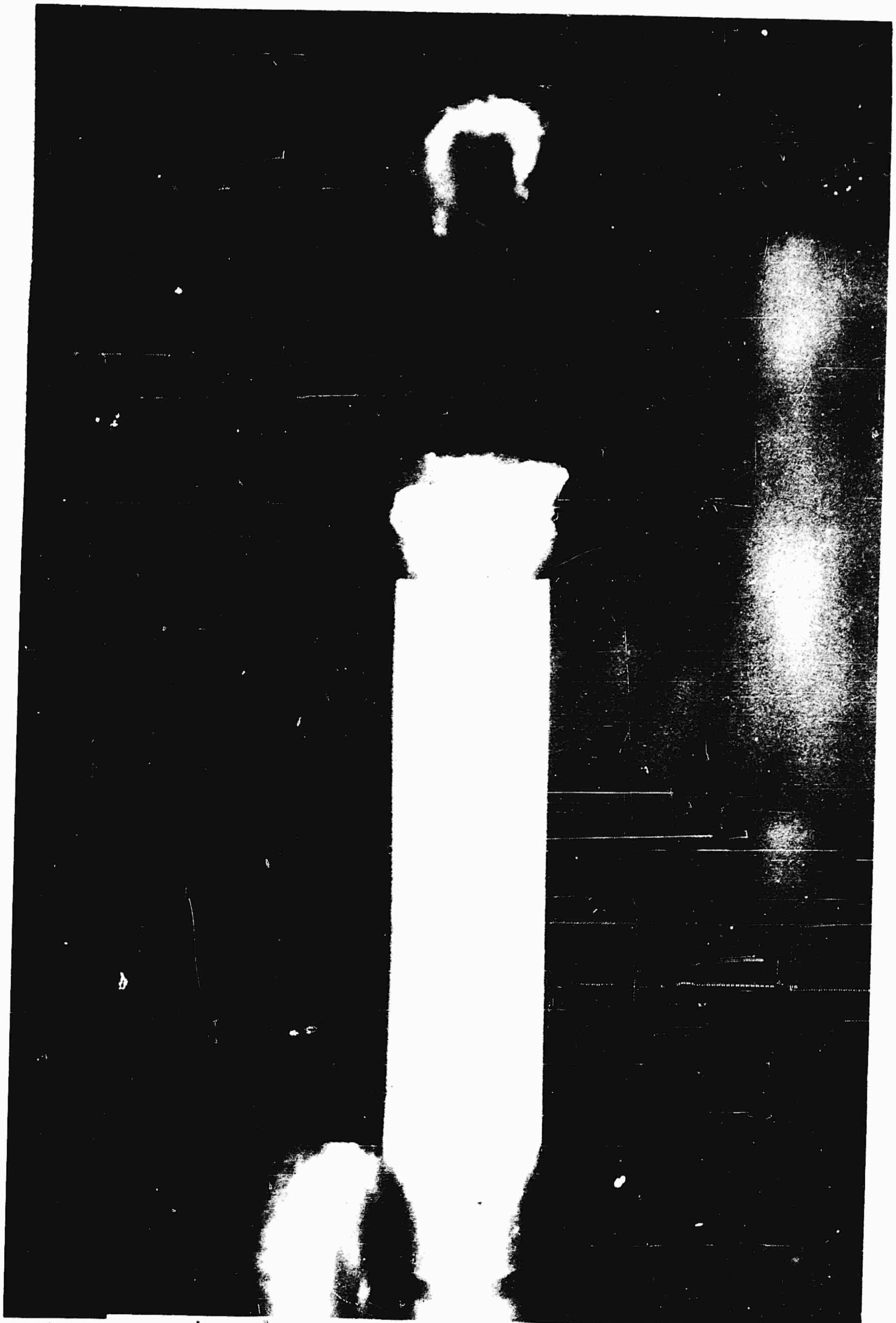
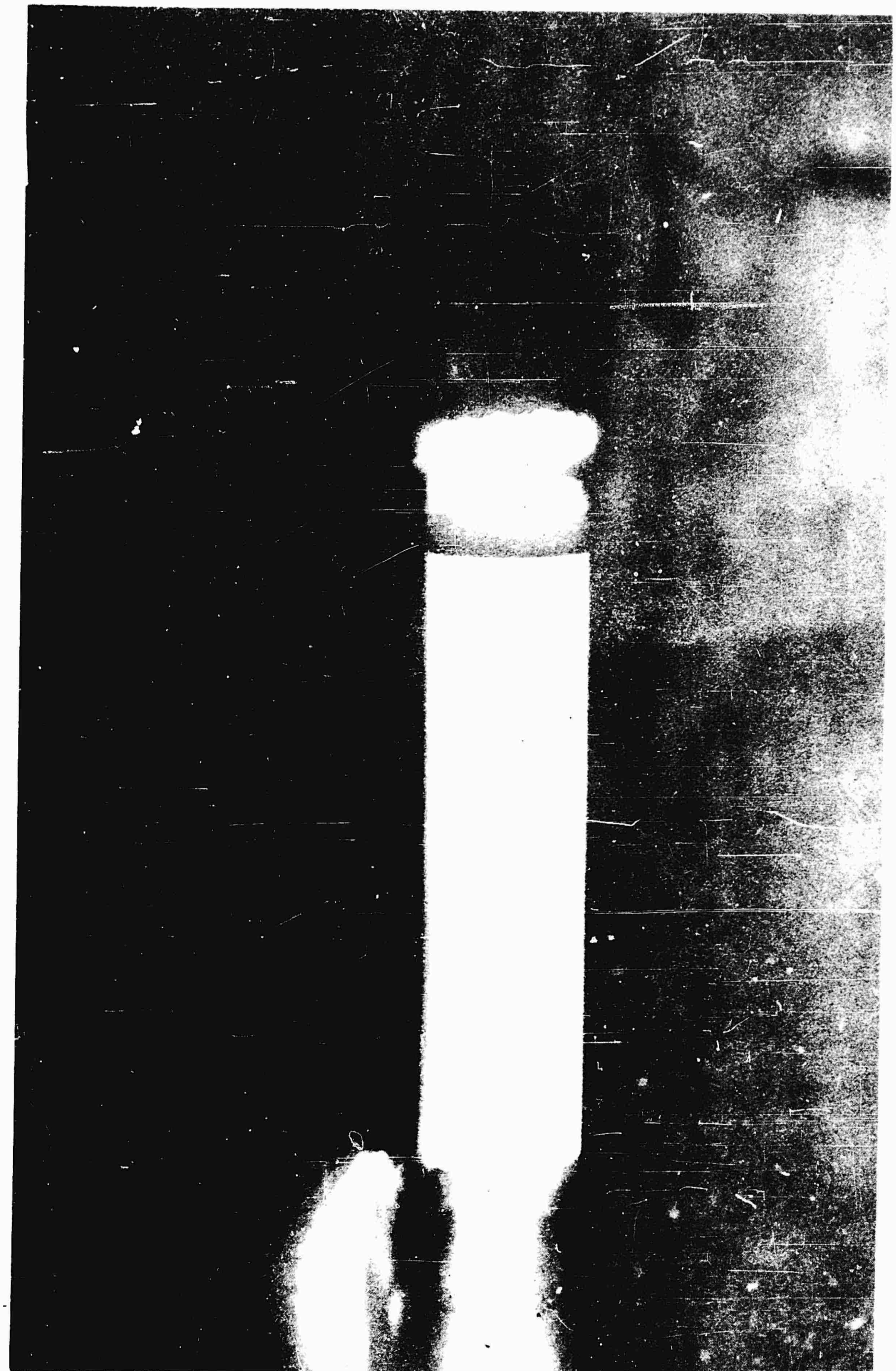


1256-0389

Microflash Photograph - Model "A", Velocity = 95.3 ft/sec



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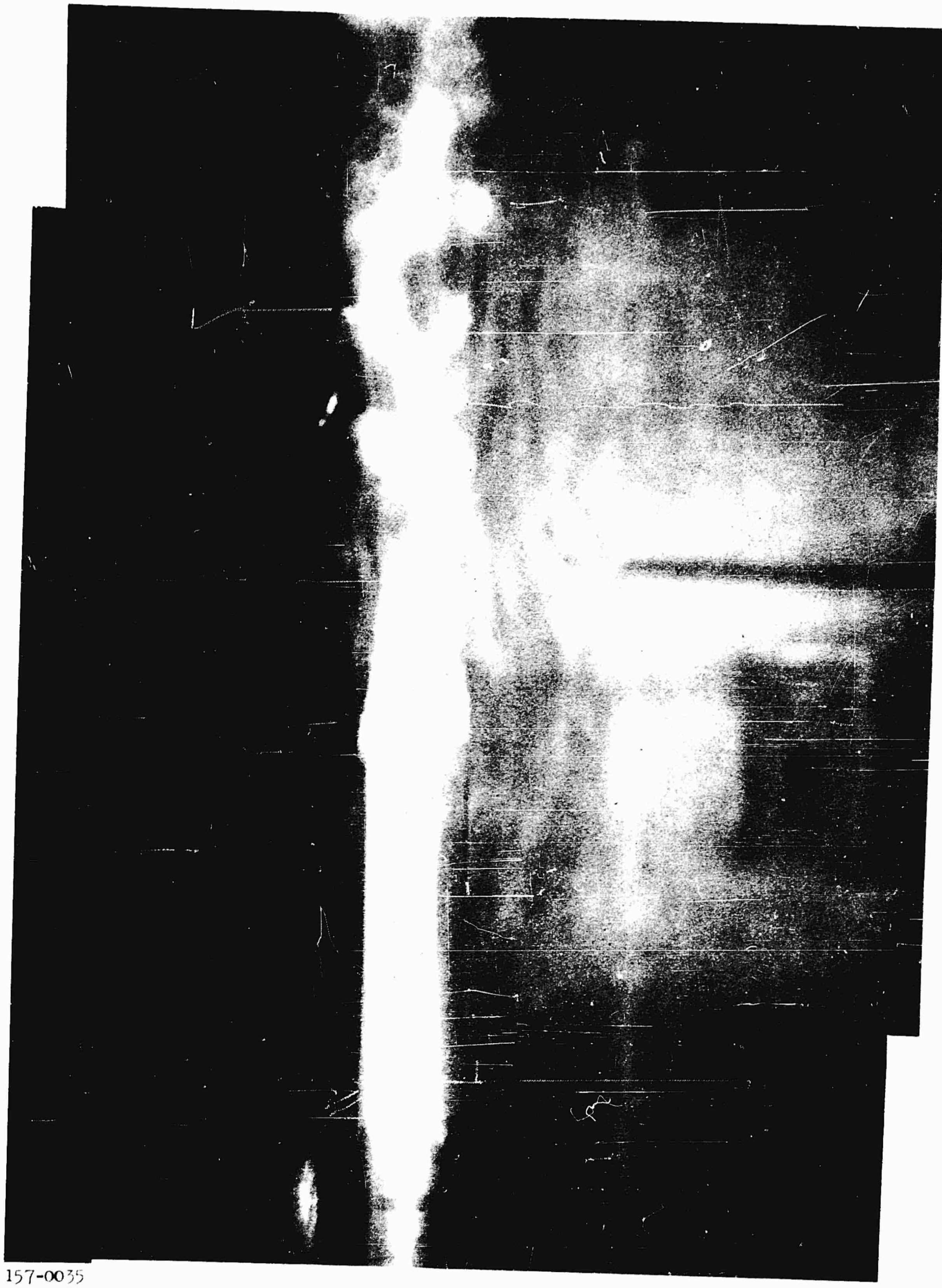
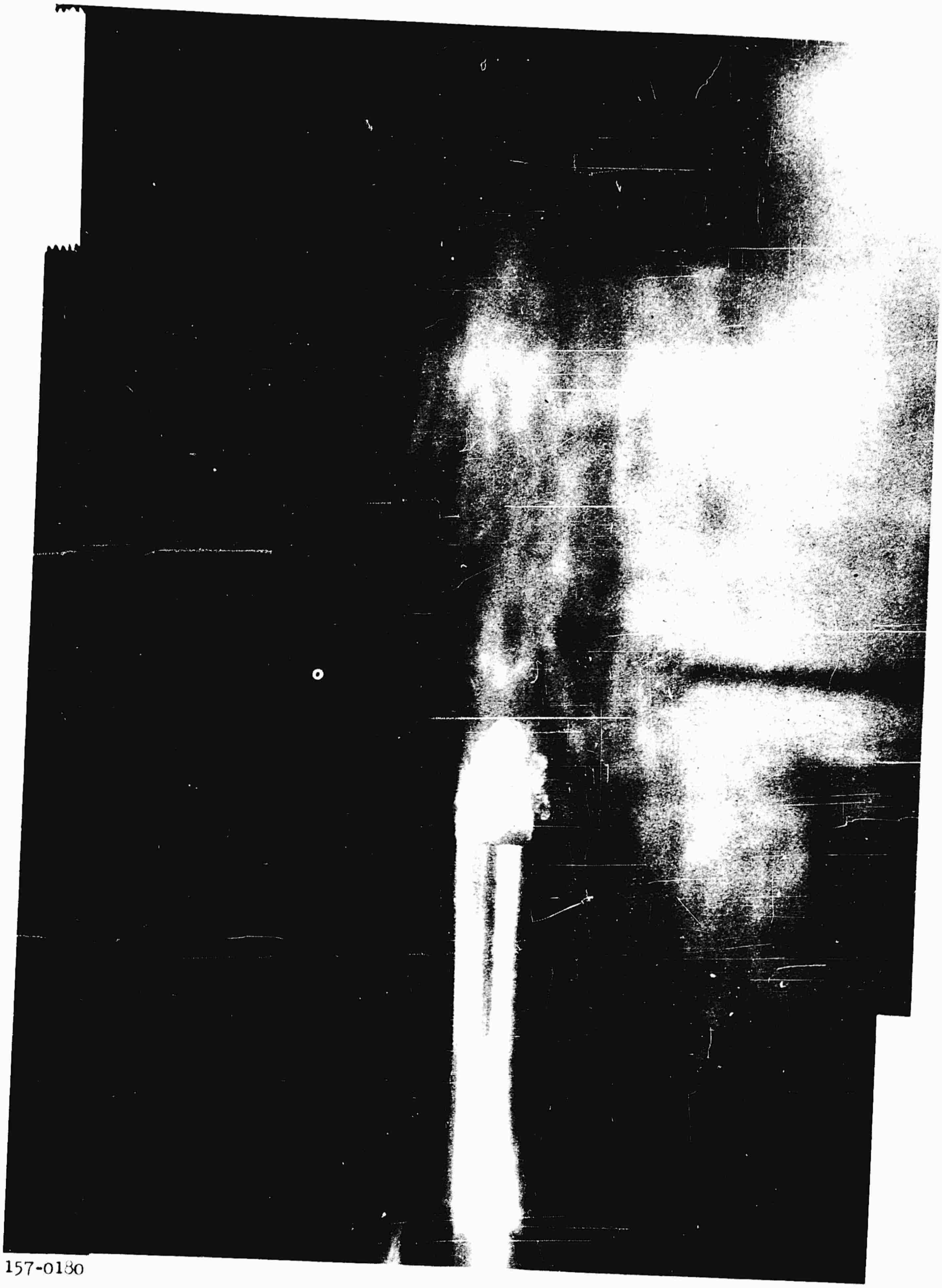
Microflash Photograph - Model "C", Velocity = 94.0 ft/sec



157-0035

Microflash Photograph - Model "D", Velocity = 91.8 ft/sec



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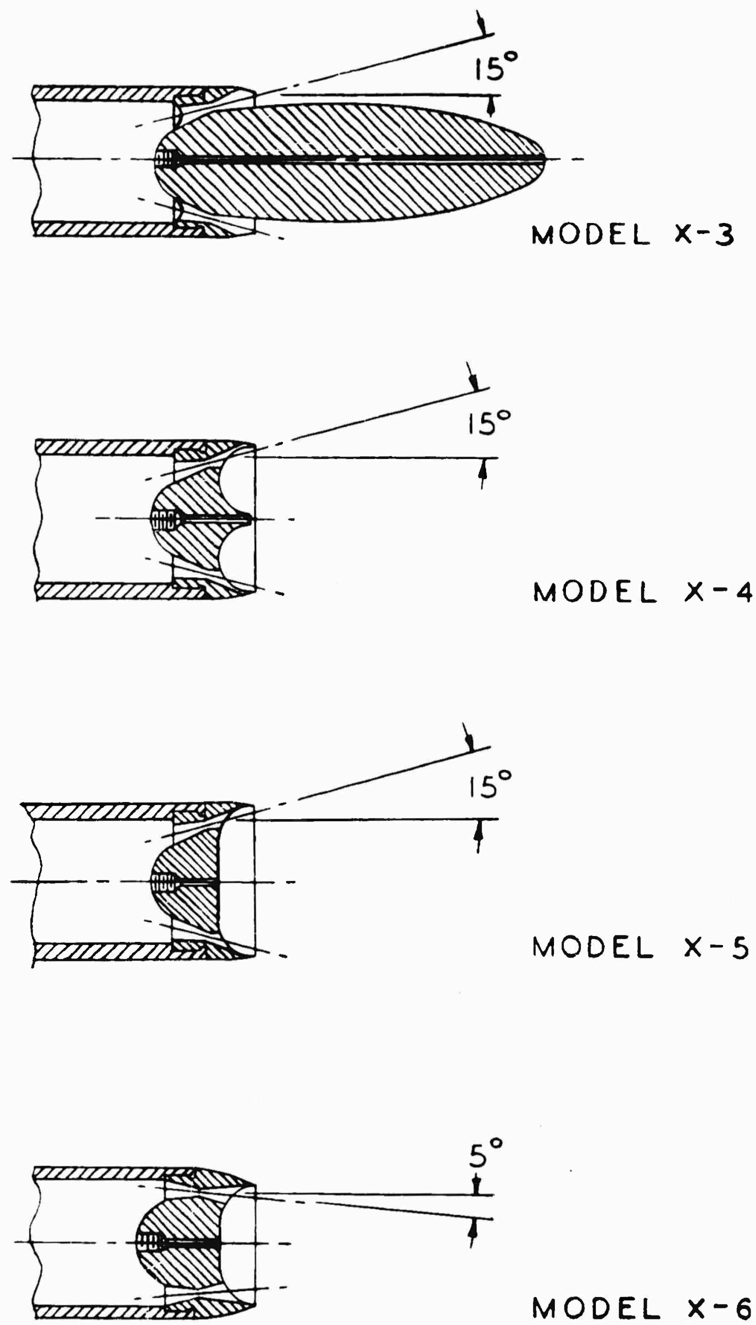
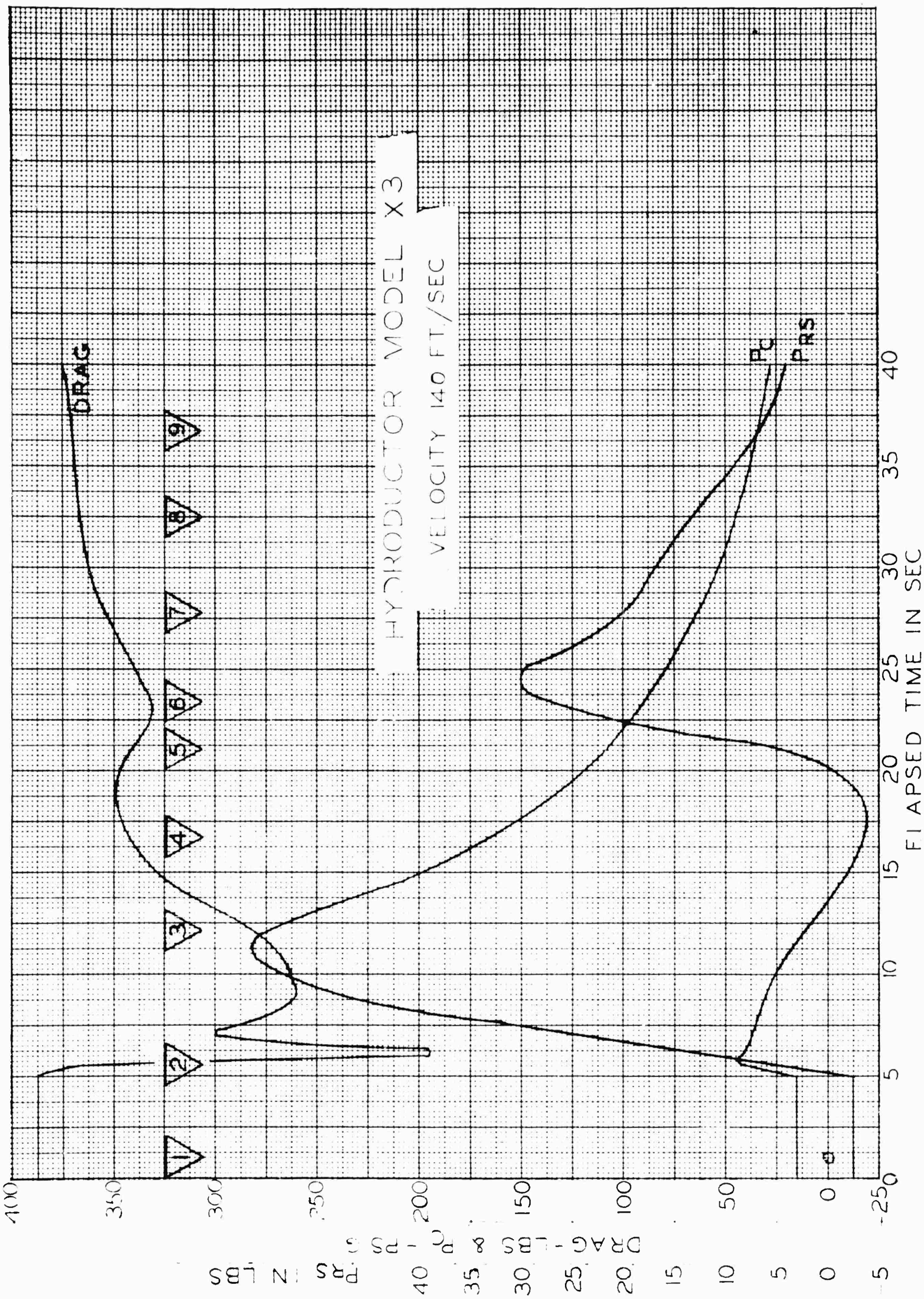
Microflash Photograph - Model "E", Velocity = 92 ft/sec

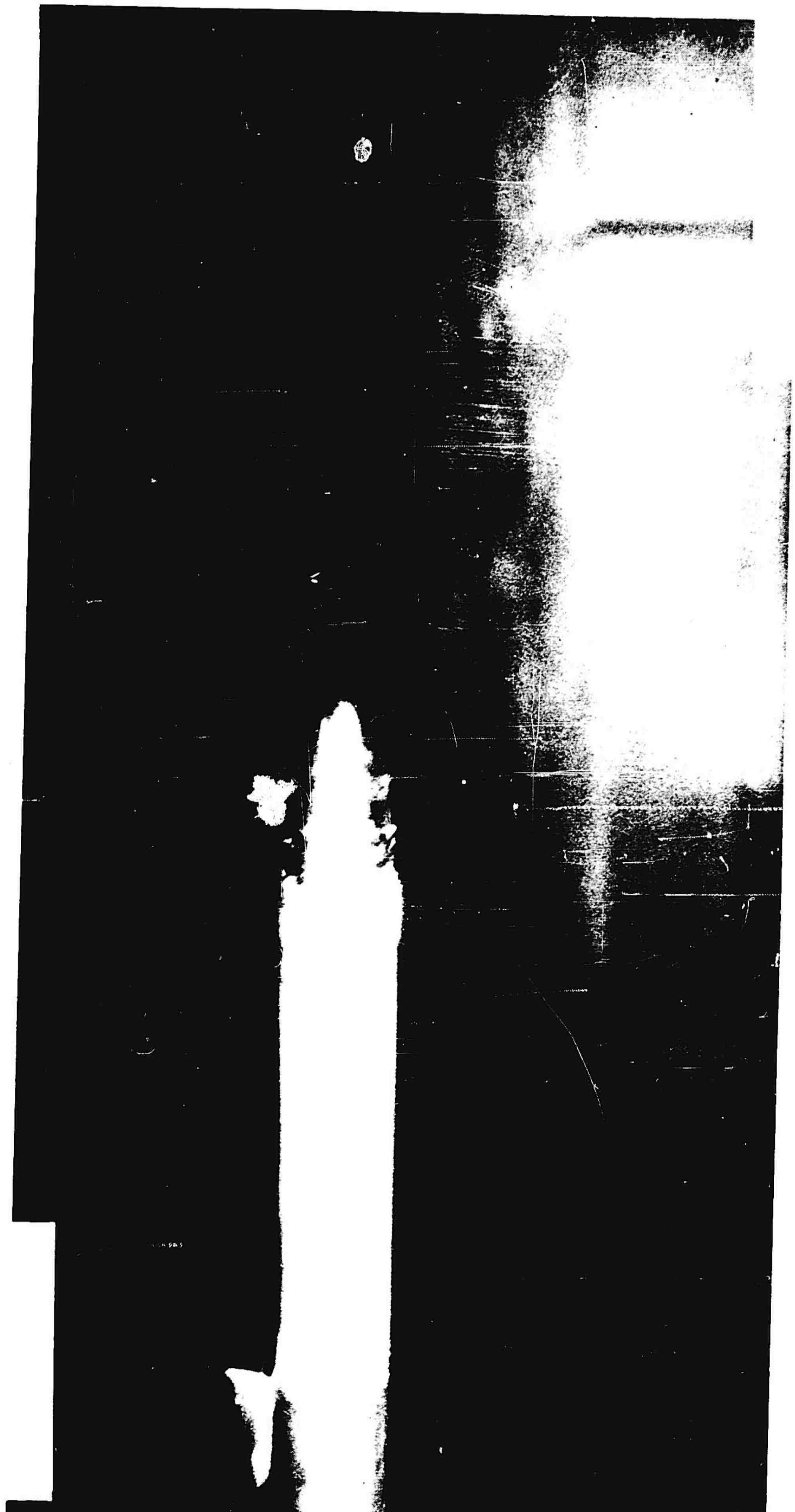


SCHEMATIC DIAGRAMS

EXTERNAL - CONDENSING
HYDRODUCTOR MODELS

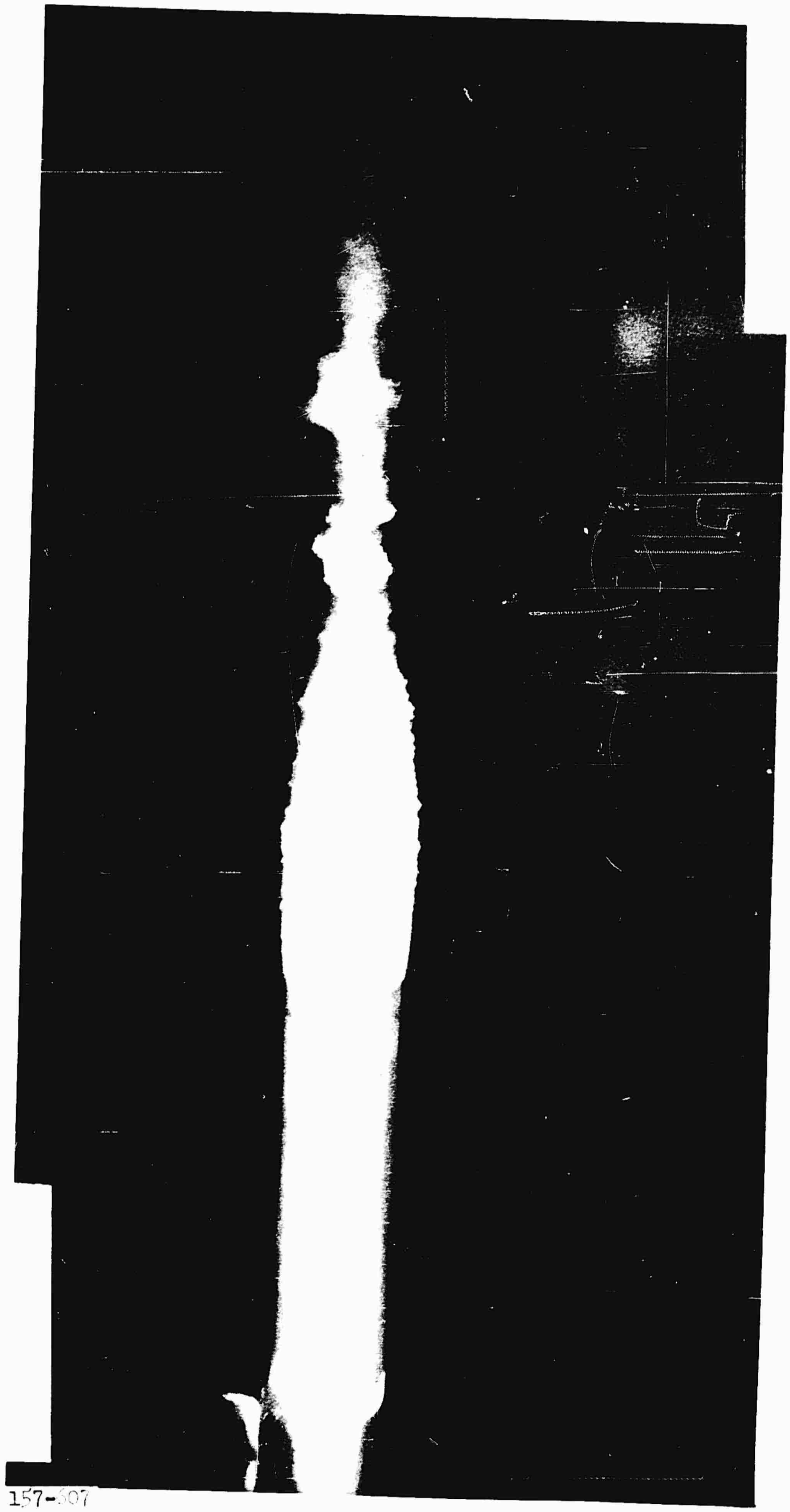


Performance Curve - Model X3 Hydroductor



157-605

Microflash Photograph No. 1 - Hydroductor Model X3



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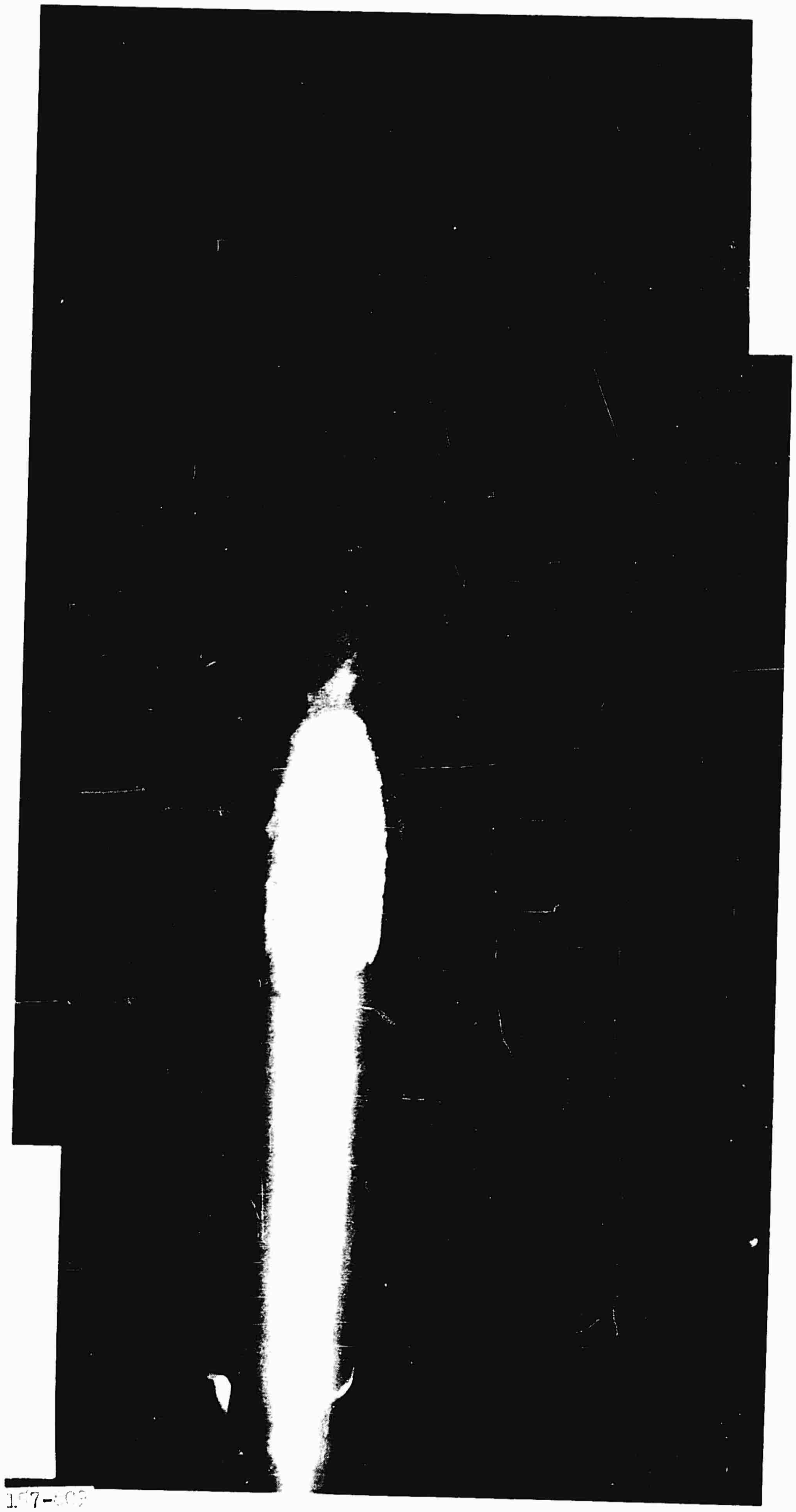
Microflash Photograph No. 3 - Hydroductor Model X3



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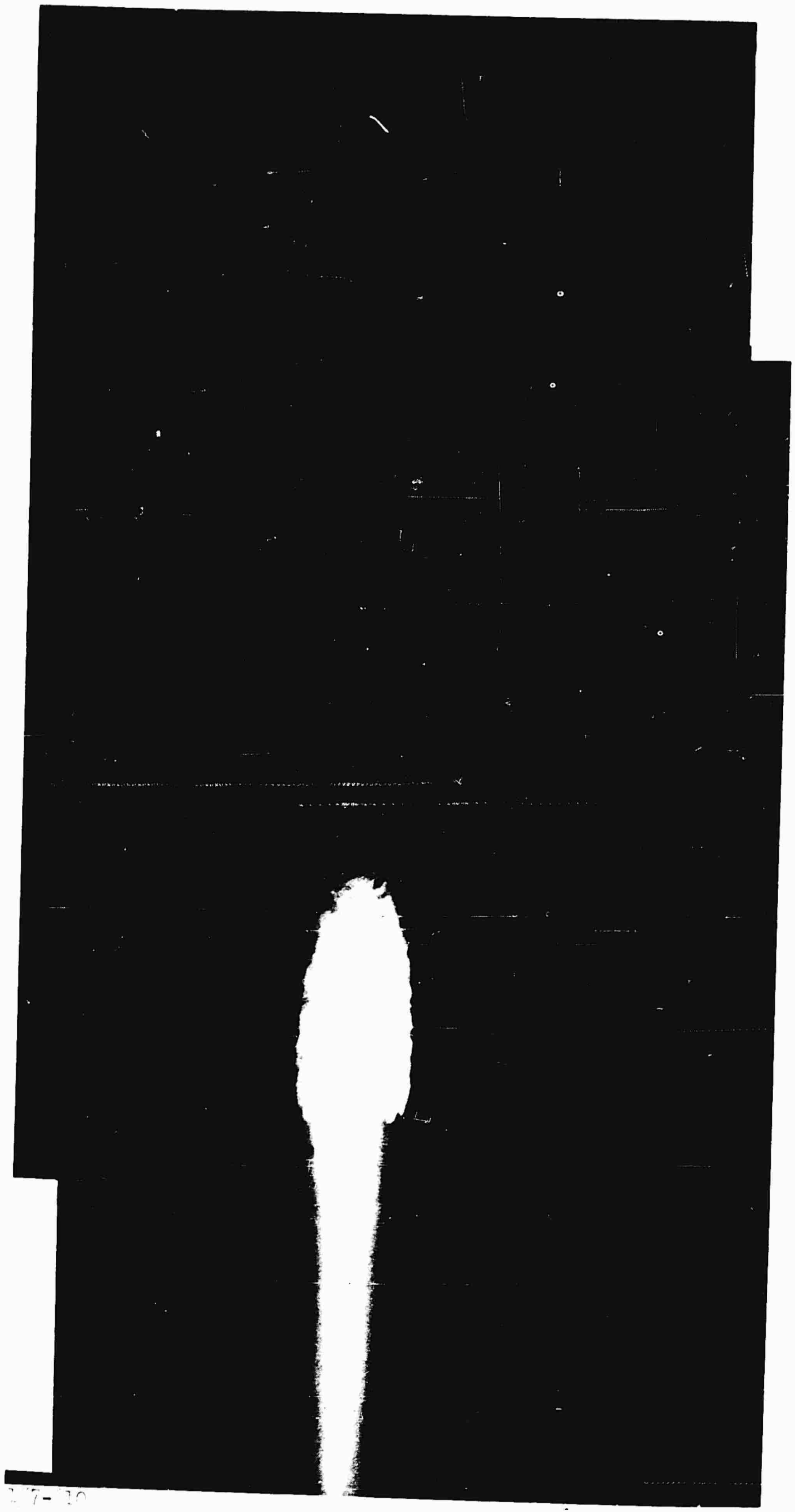
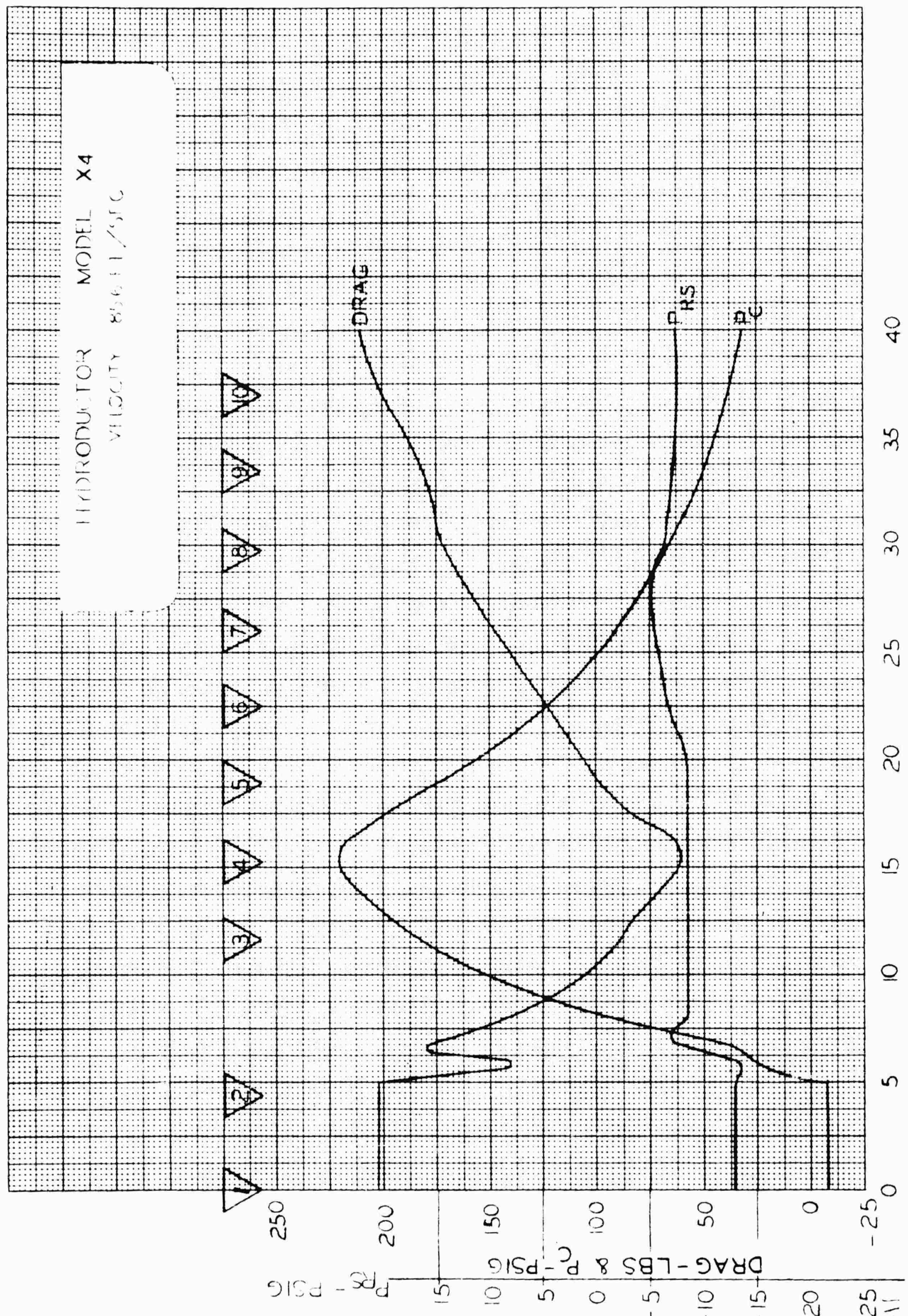
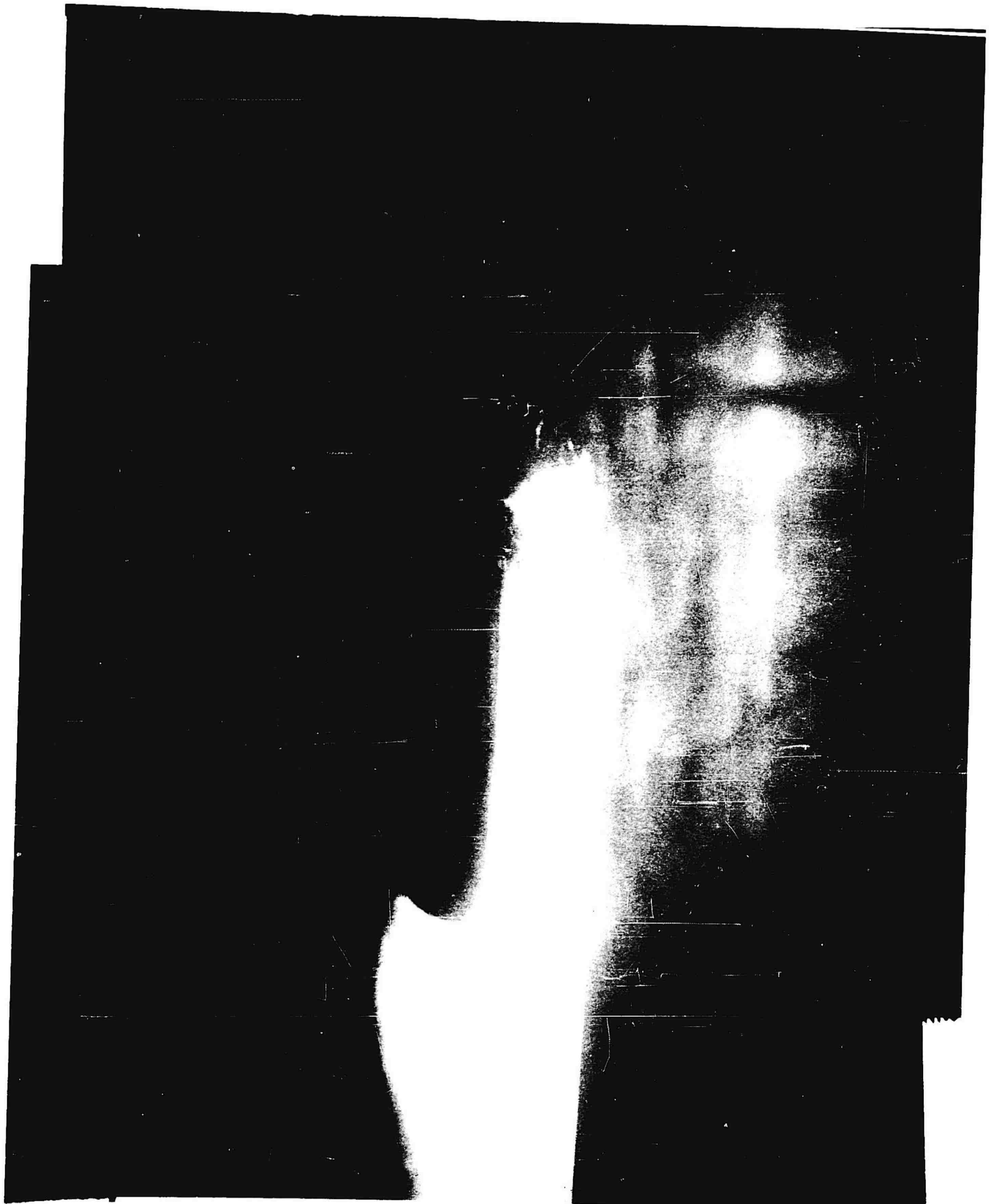


Microflash Photograph No. 6 - Hydroductor Model X3

UEC-4694
PER NO 1000H



Performance Curve - Hydroductor Model X4 - Velocity 85.6 ft/sec



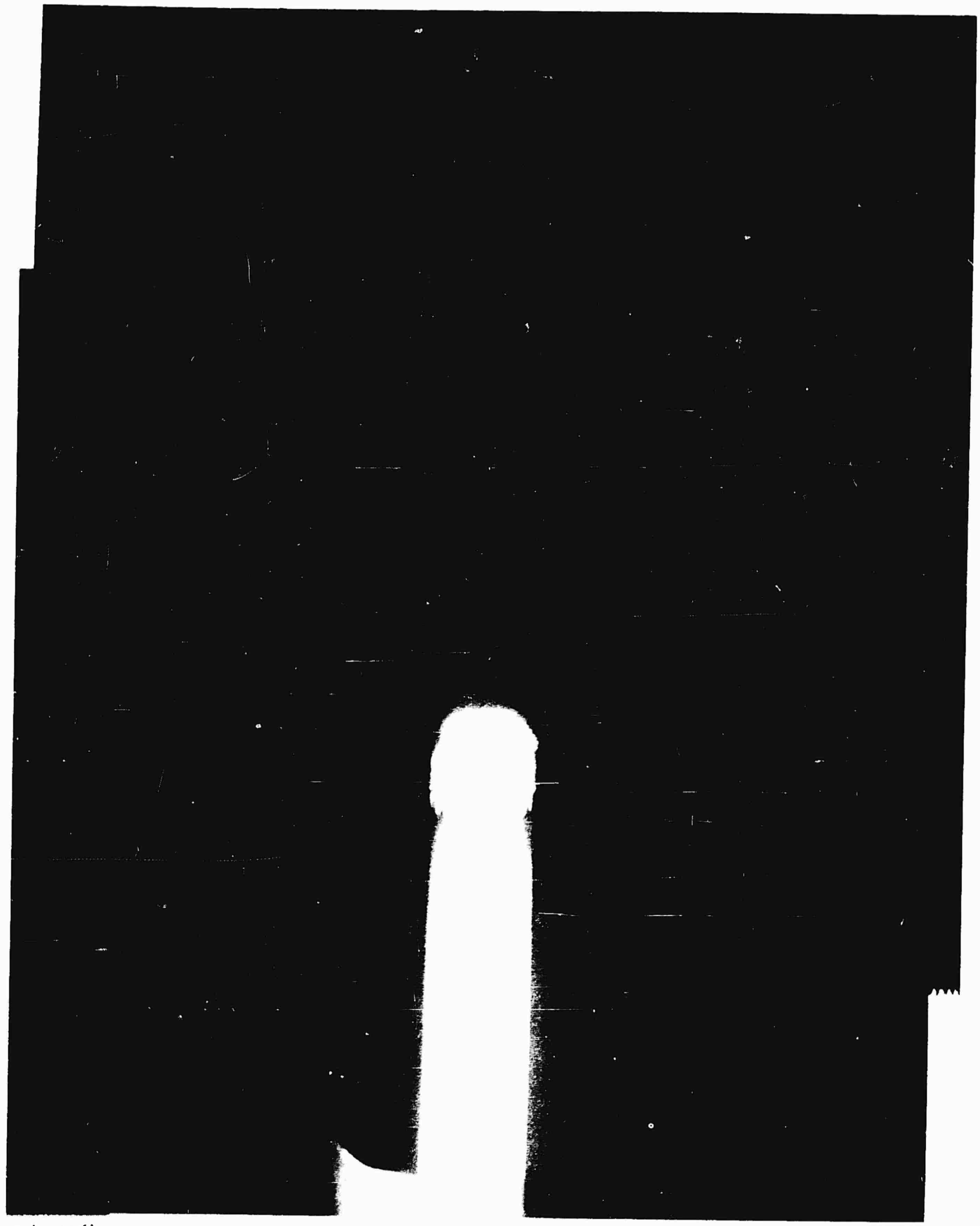
157-1158

Microflash Photograph No. 1 - Hydroductor Model X4

Figure 17

157-1161

Microflash Photograph No. 4 - Hydroductor Model X4



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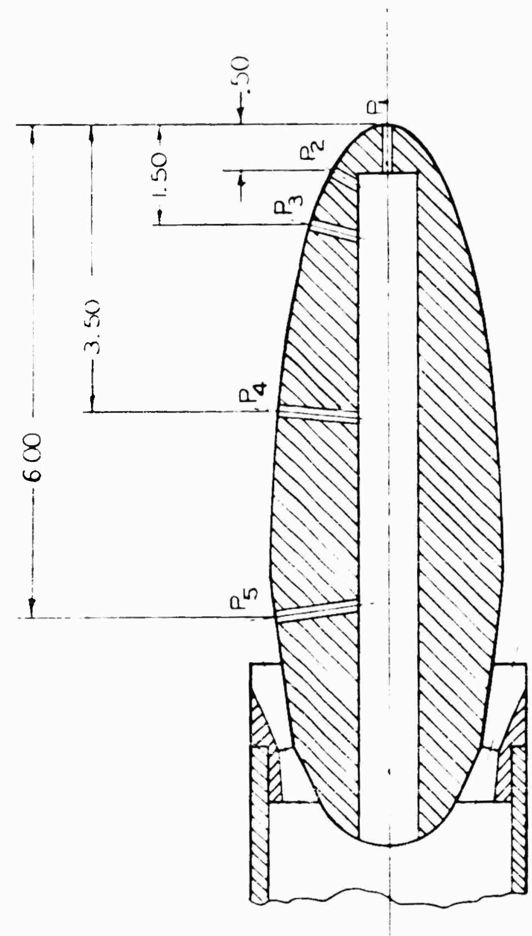
Microflash Photograph No. 7 - Hydroducotr Model X4

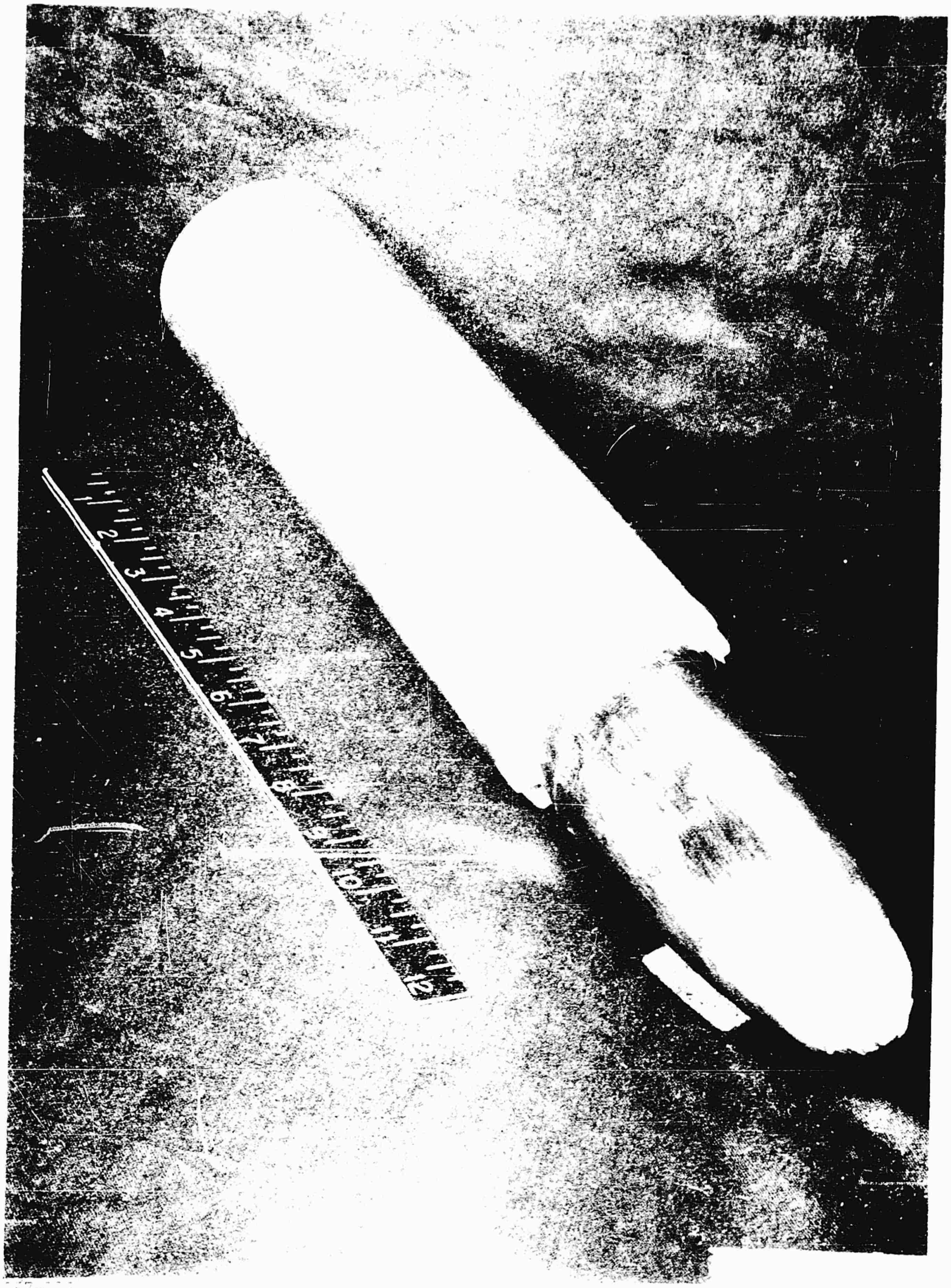
257-1137

External-Condensing Hydroductor Model X5

E.S./RV 6-3-57 UFC 4783



EXTERNAL CONDENSING HYDRODUCTOR
MODEL X3
LOCATION OF PRESSURE-SENSING POINTS



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Hydroductor [illegible] Pressure Taps Drilled in Afterbody

E.H./R.V. 6-24-57 DEC 4791

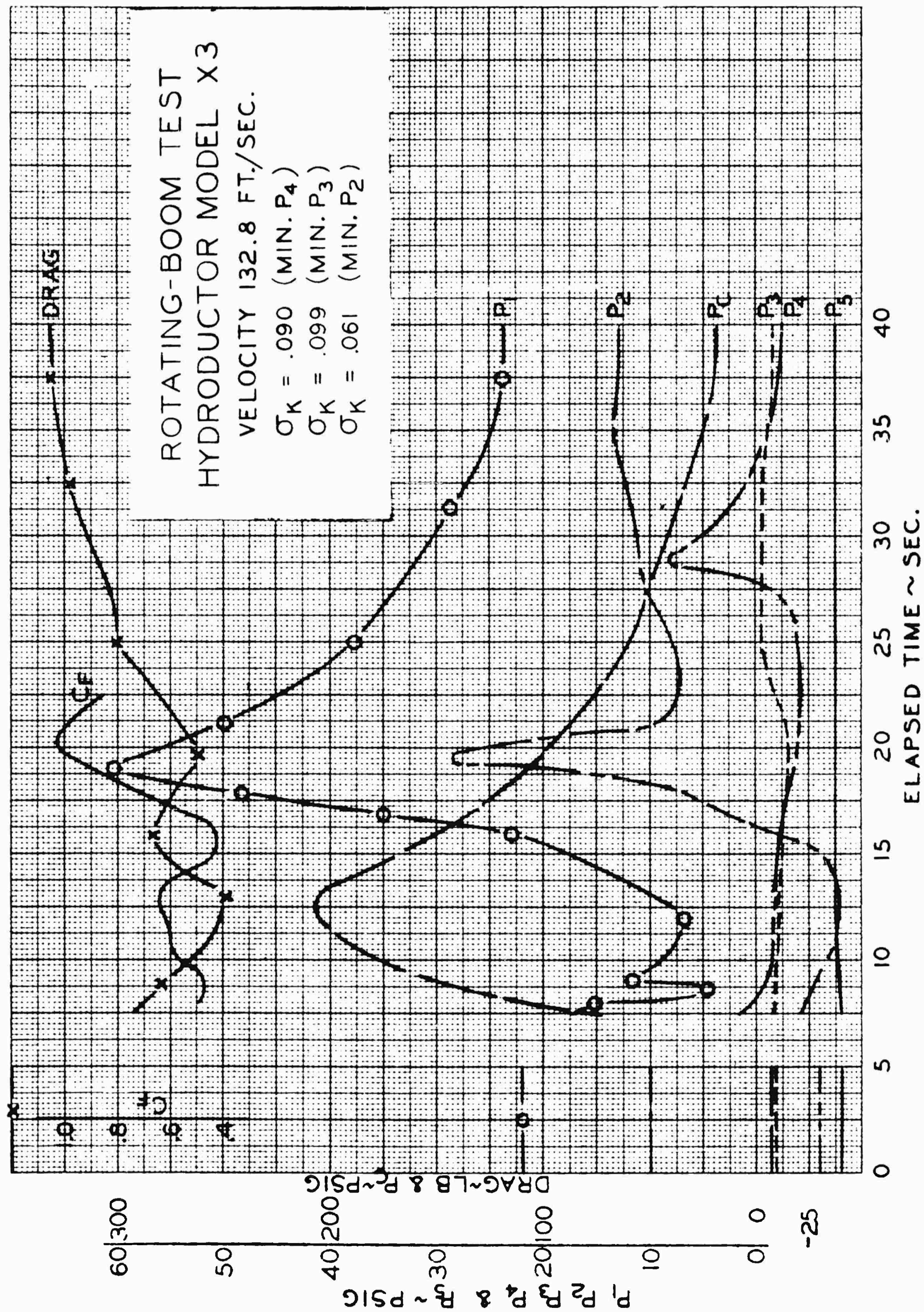


Figure 23

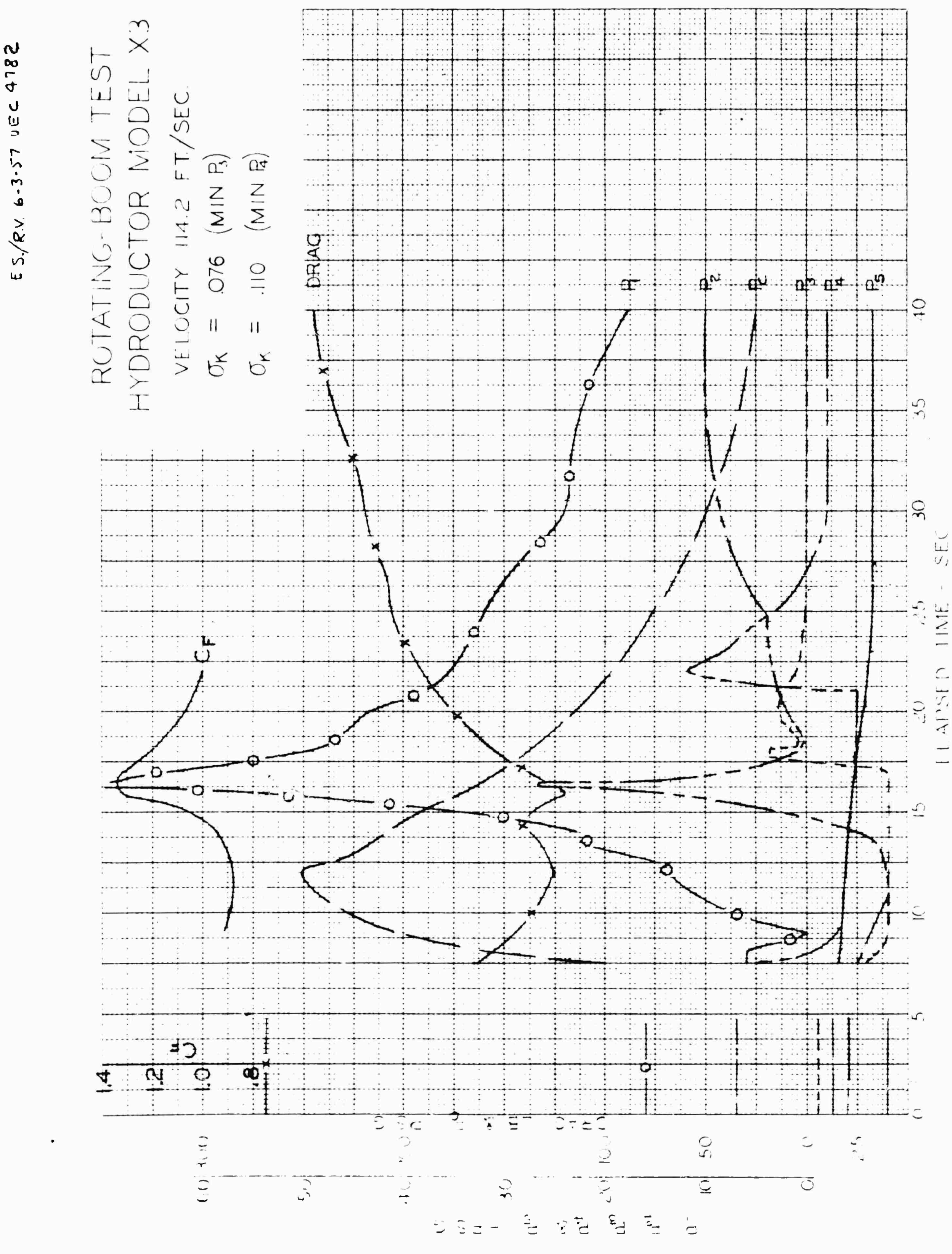
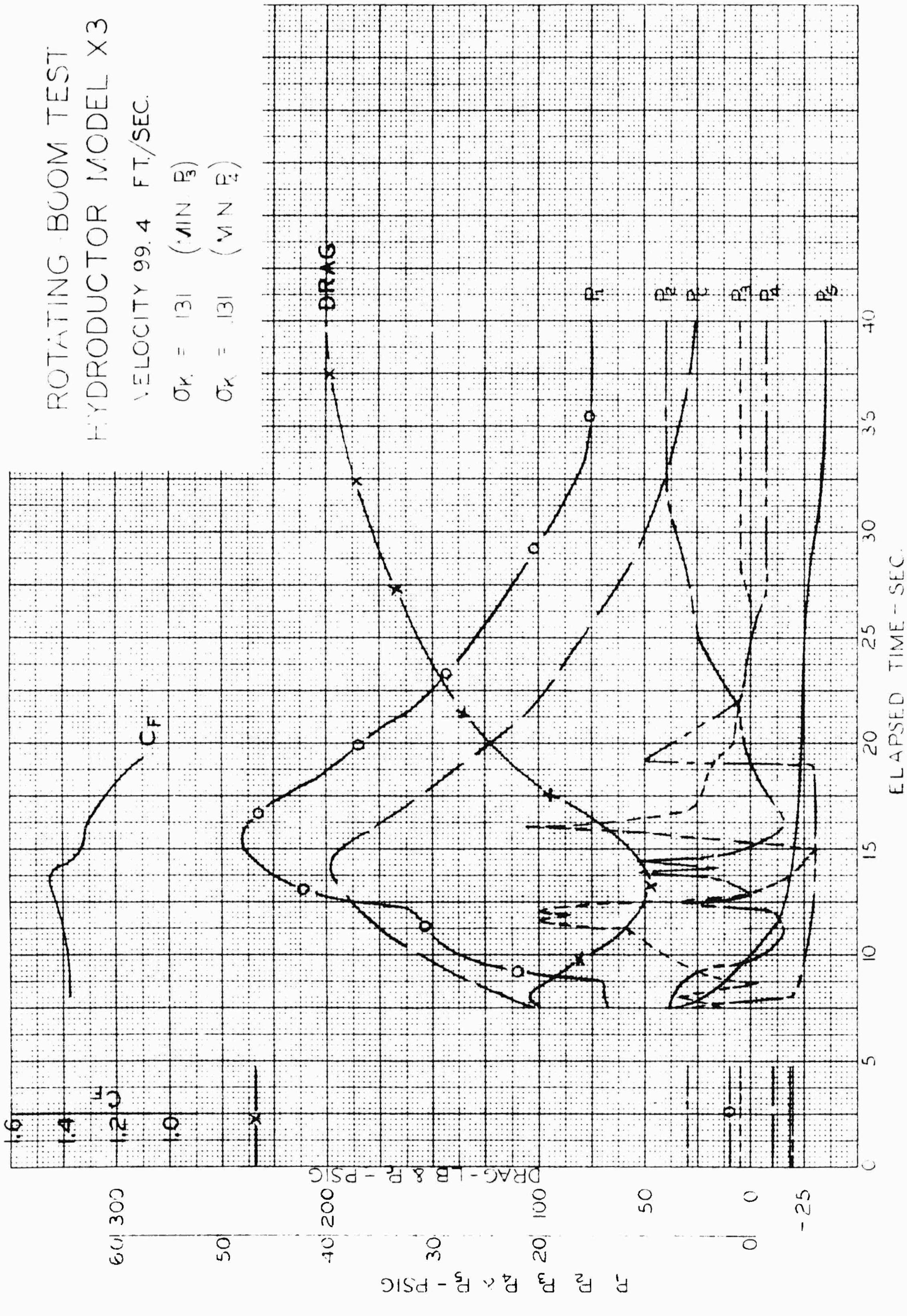
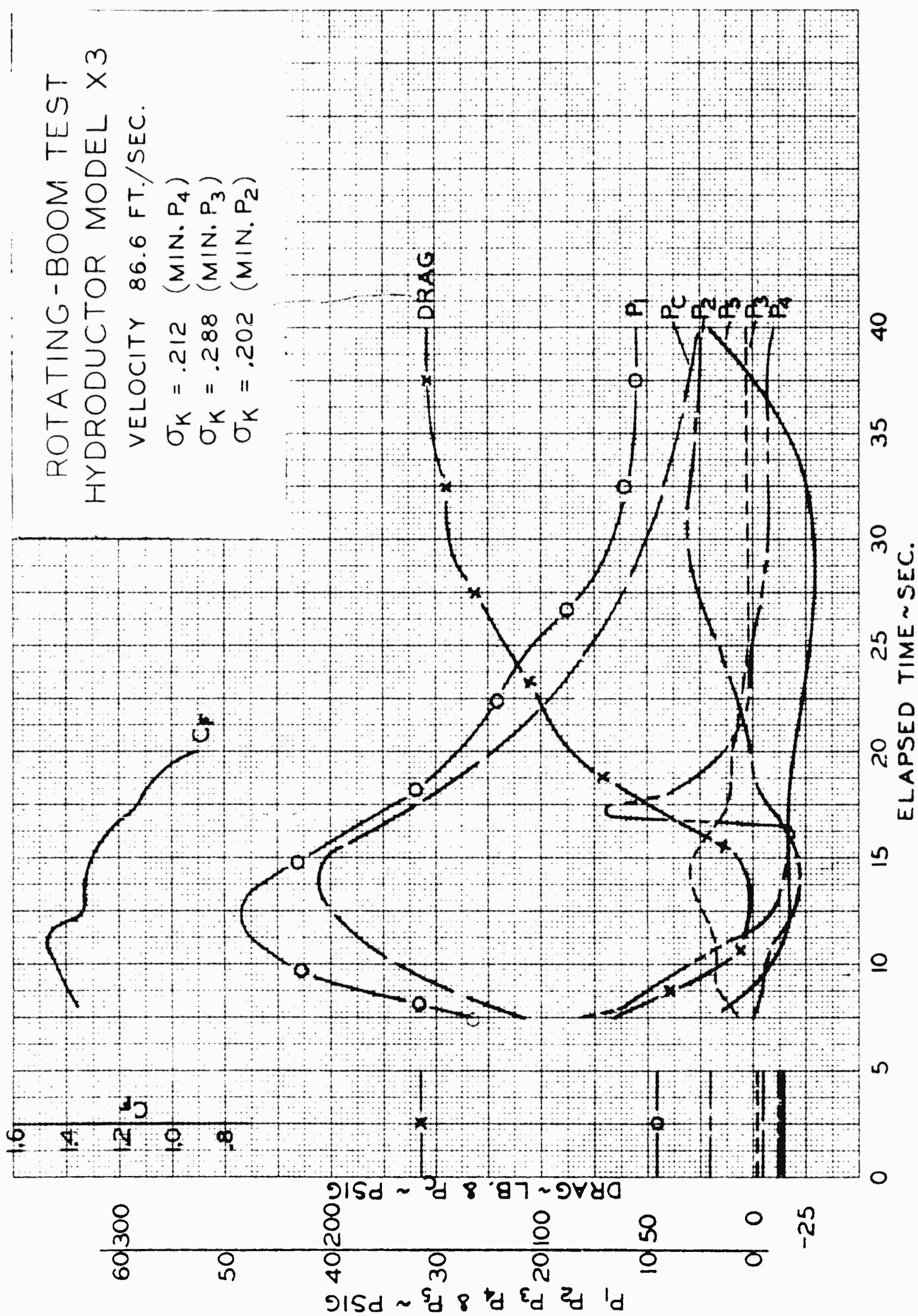

ES/RV 6-3-57 UEC 4782
ROTATING-BOOM TEST
HYDRODUCTOR MODEL X3
VELOCITY 114.2 FT/SEC
σK = .076 (MIN P3)
σK = .110 (MIN P4)
DRAG
CF
ELAPSED TIME - SEC

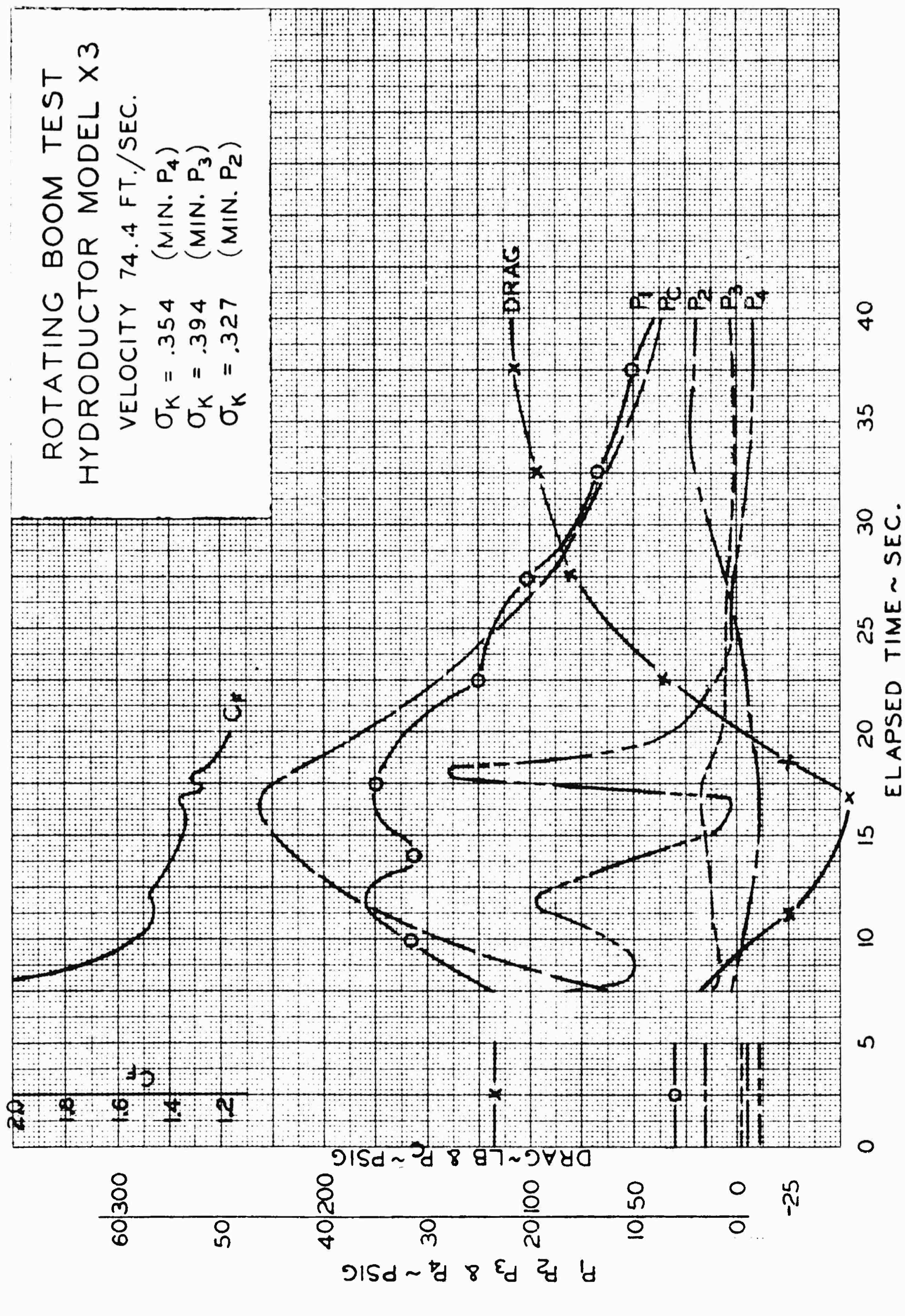
Figure 24


ROTATING BOOM TEST
HYDRODUCTOR MODEL X3
VELOCITY 99.4 FT./SEC.
σK = .131 (MIN P3)
σK = .131 (MIN P4)
DRAG
CF
ELAPSED TIME - SEC.
DRAG - LB & PC - PSIG
P1 P2 P3 P4 & P5 - PSIG

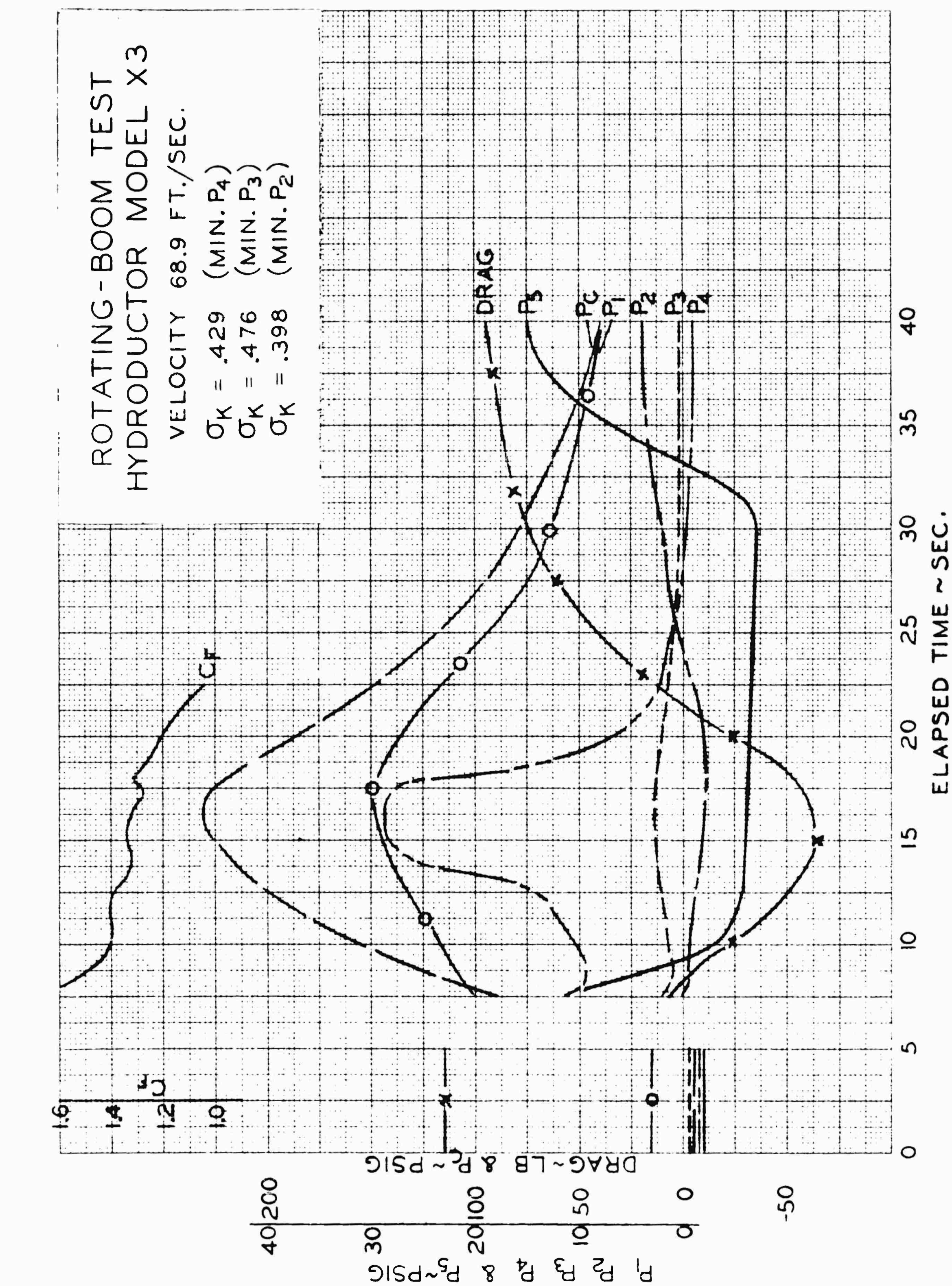
E.H./R.V. 6-24-57 URC 4792



E.H/R.V 6-24-57 UEC #4793



E.H./R.V. 6-24-57 UEC 4794



E.H./R.V. 6-24-57 DEC 4795

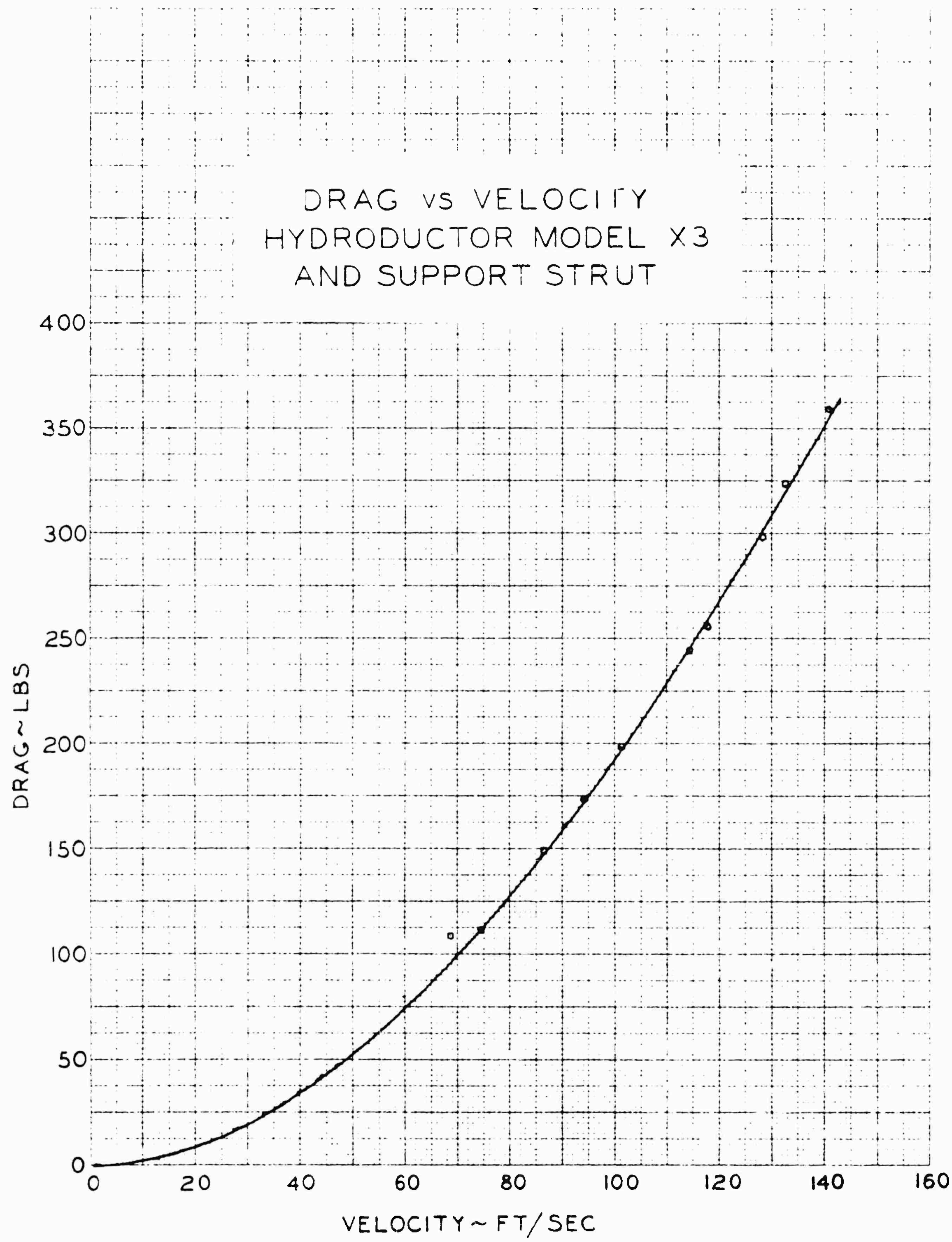
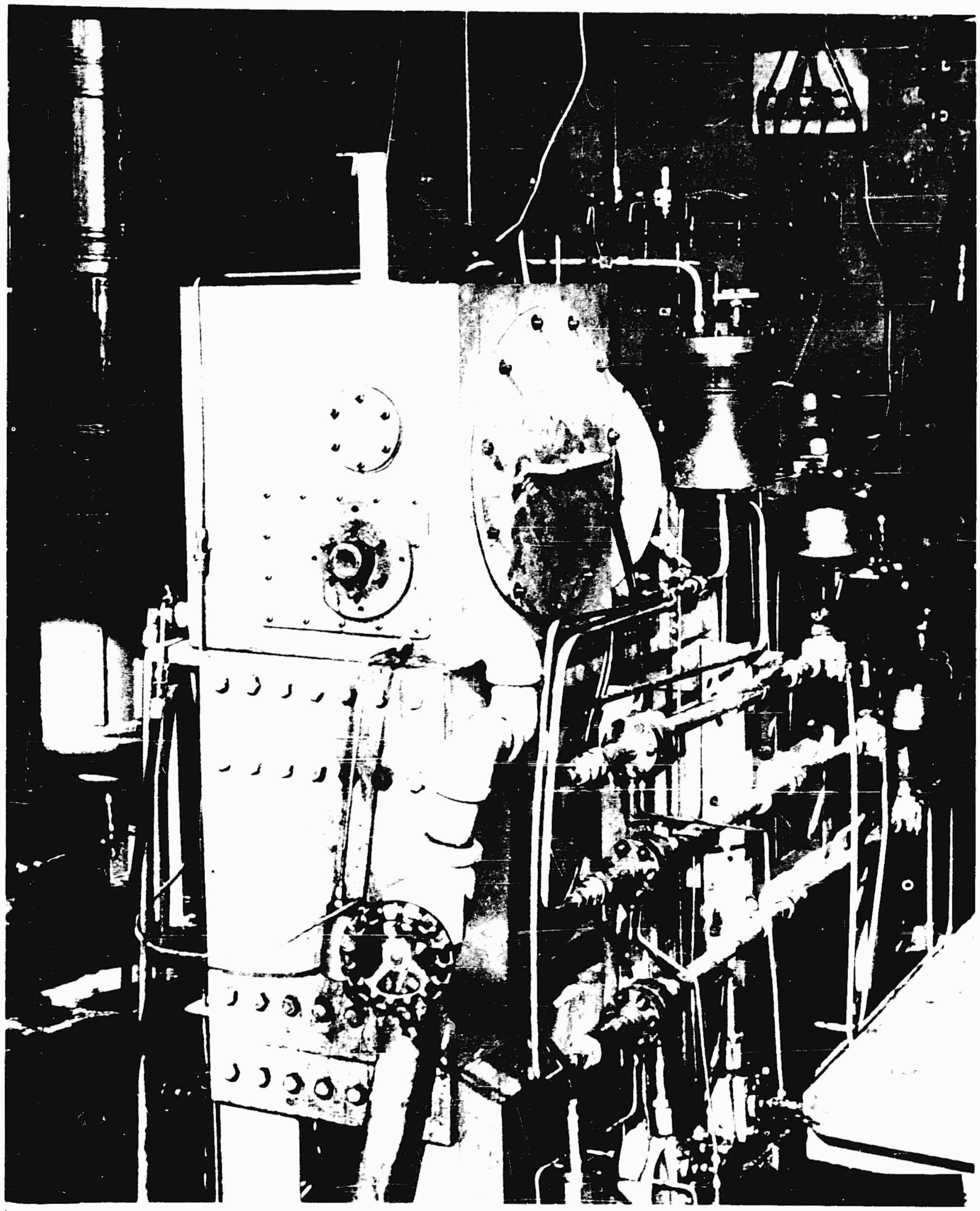
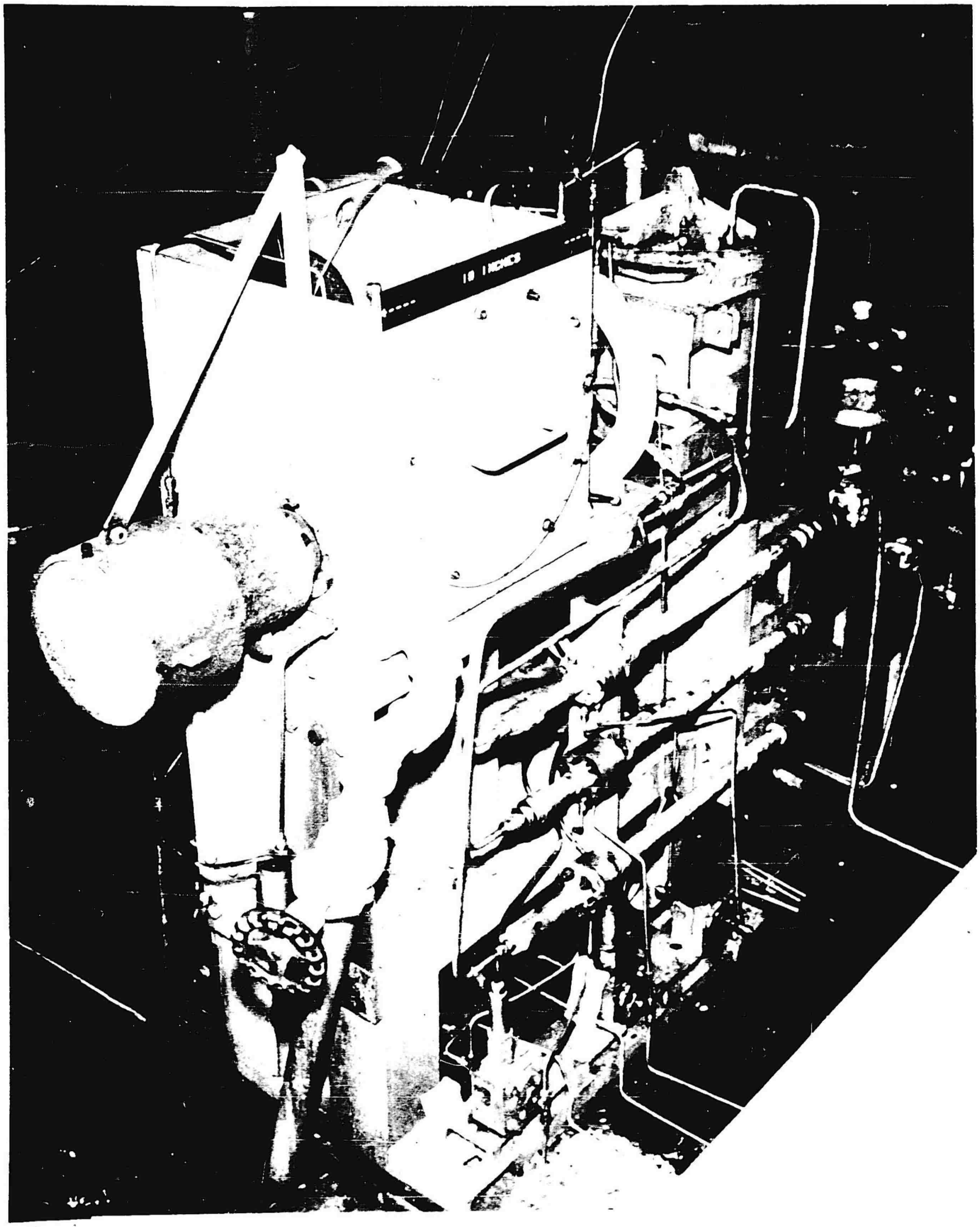


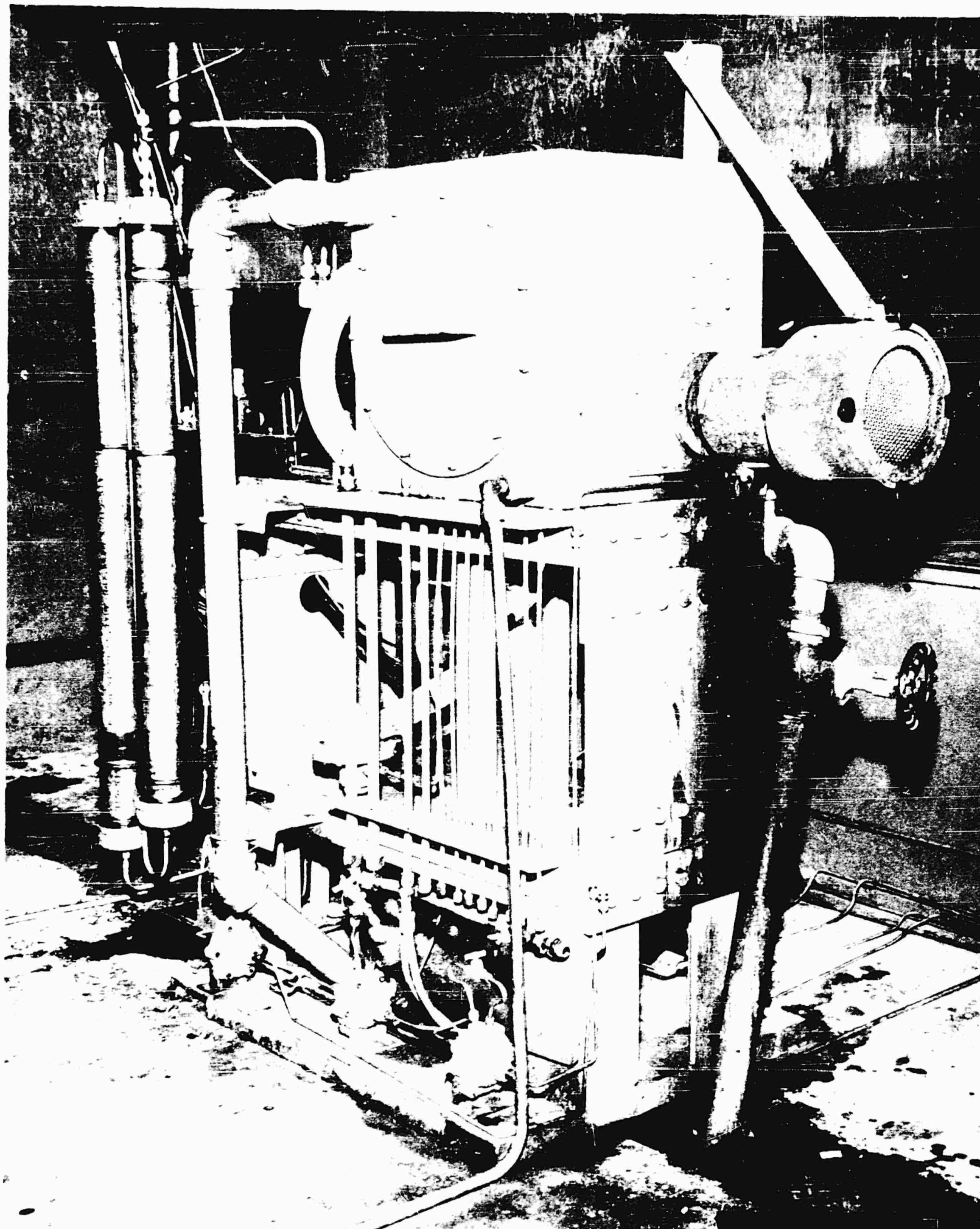
Figure 29



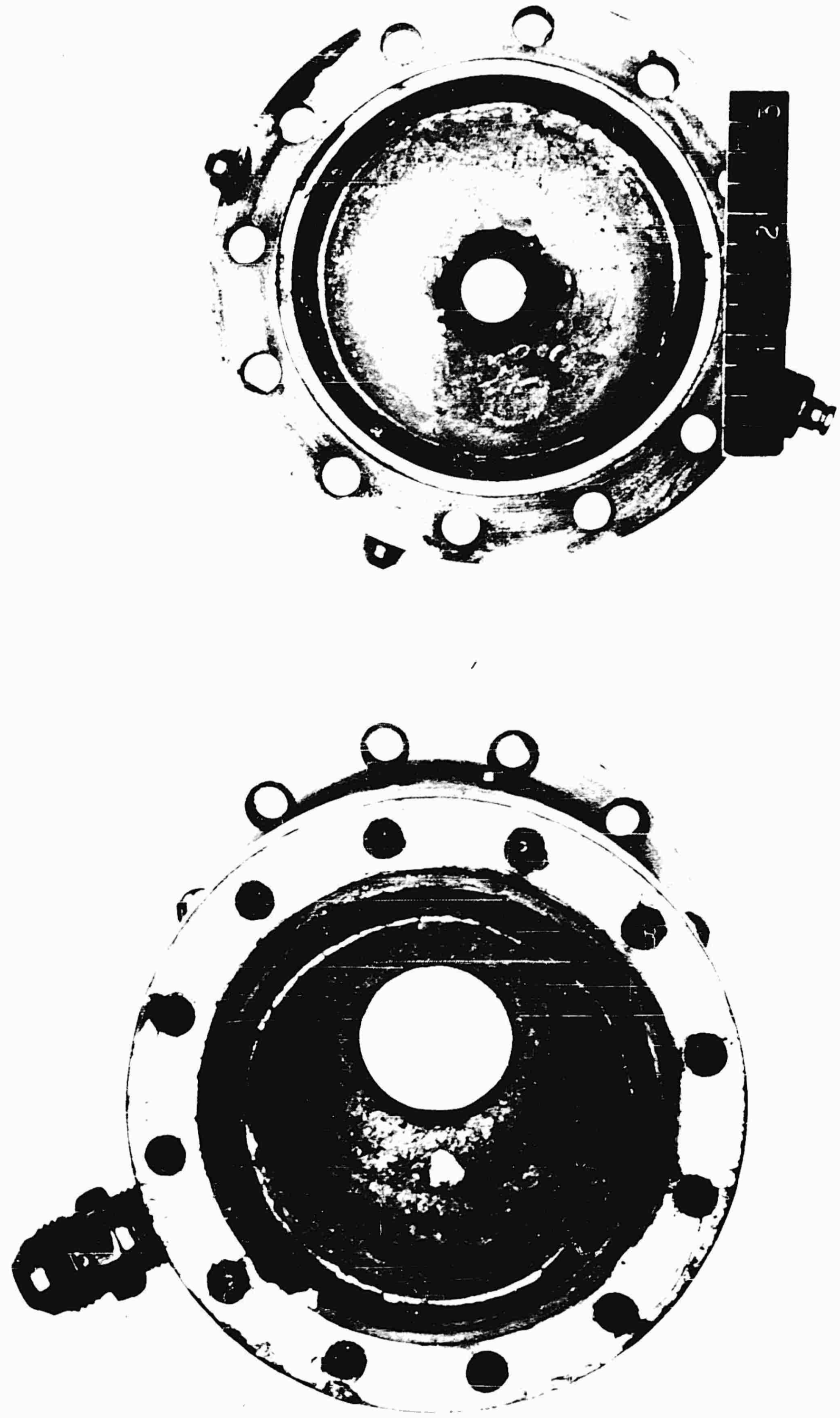
Ion Exchange Unit - 6 in. OD x 6 in. on Thrust Stand



Ion Exchange Unit - 12.5-in. OD x 5.5 in. on Thrust Stand

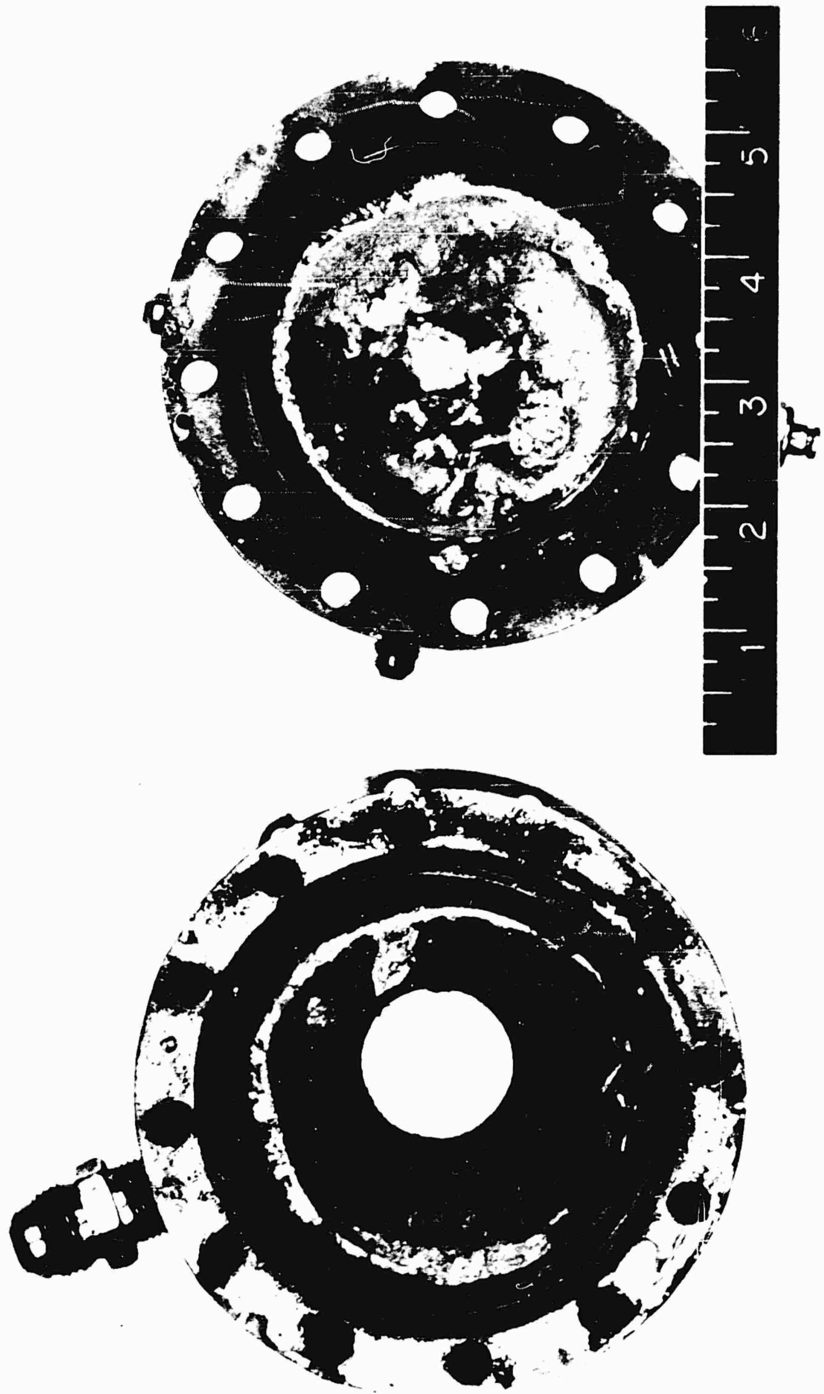


Ion Exchange Unit - 3-in. OD x 8 ft on Thrust Stand



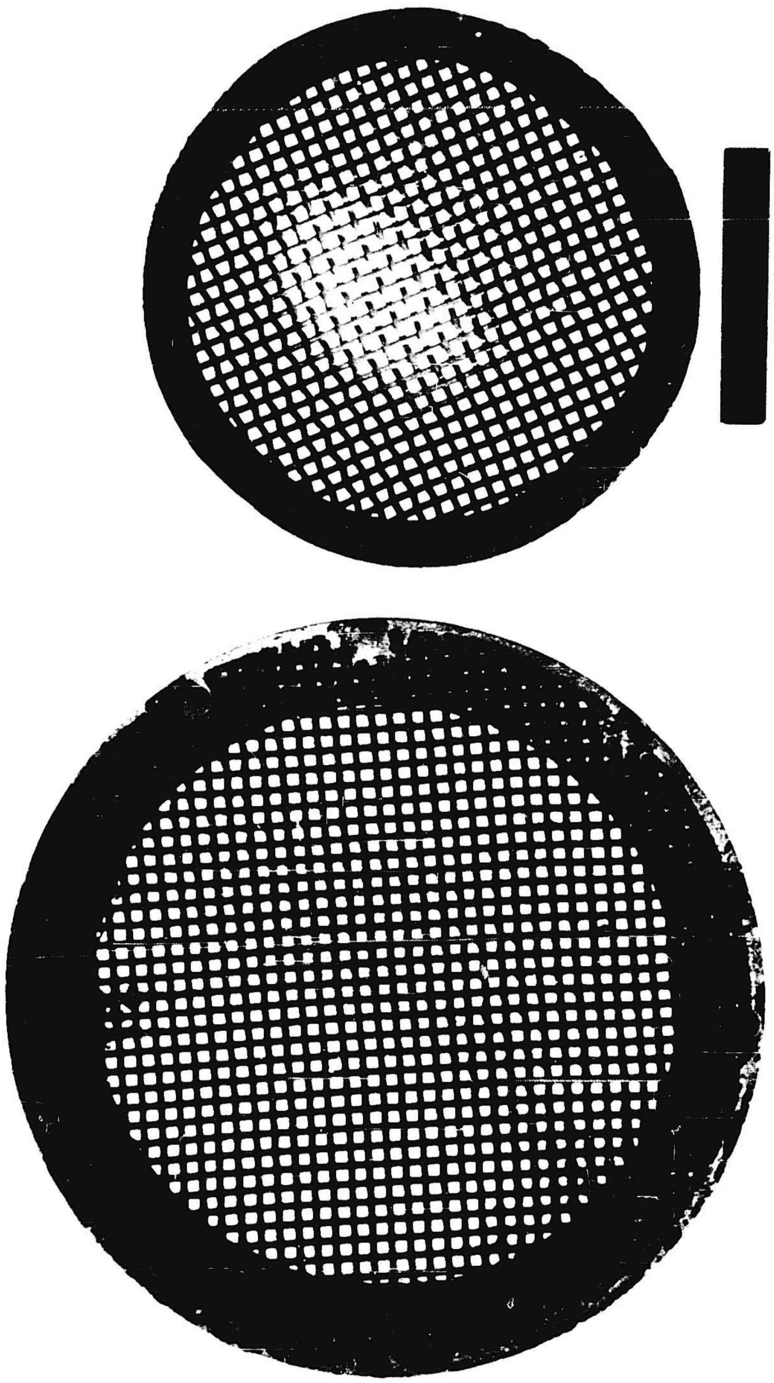
Solids Deposited in Combustion Chamber During Run No. 17

1256-0212



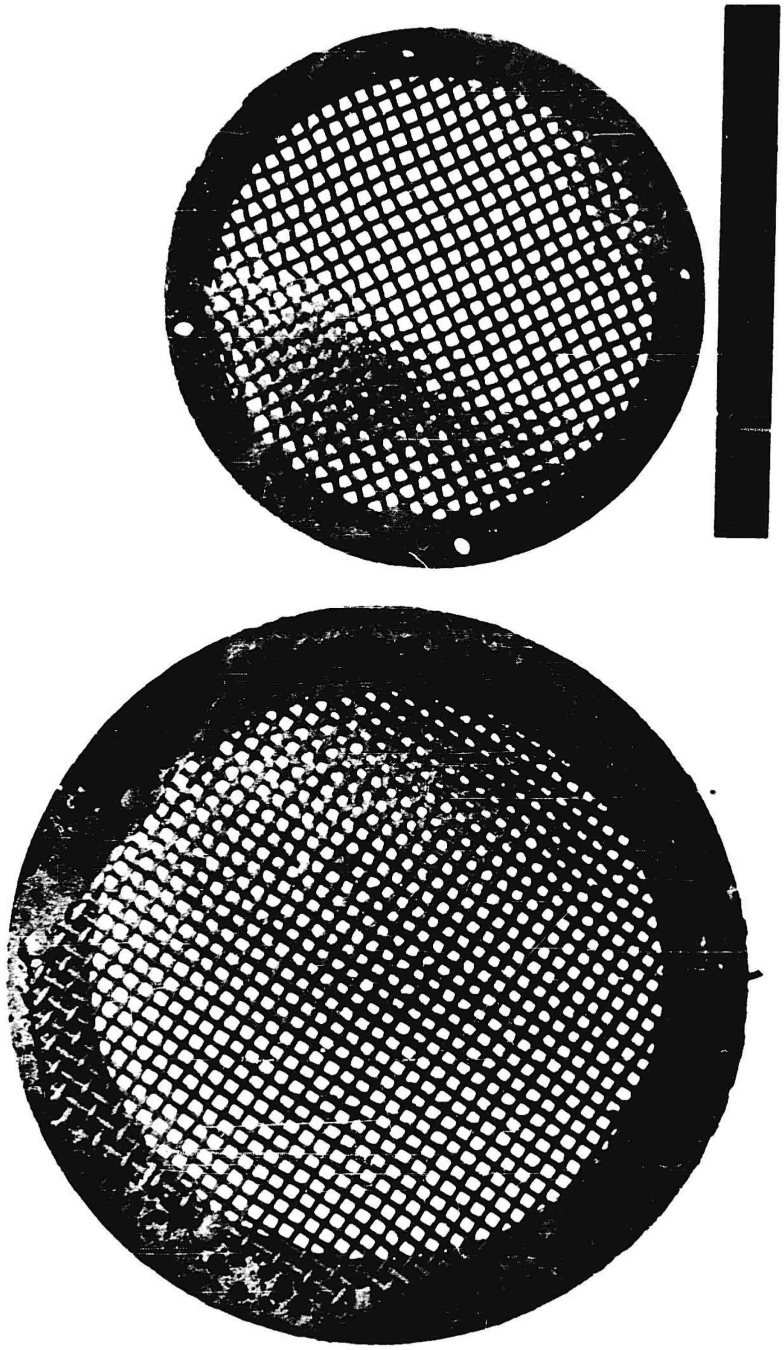
357-345

Solids Deposited in Combustion Chamber During Run No. 25



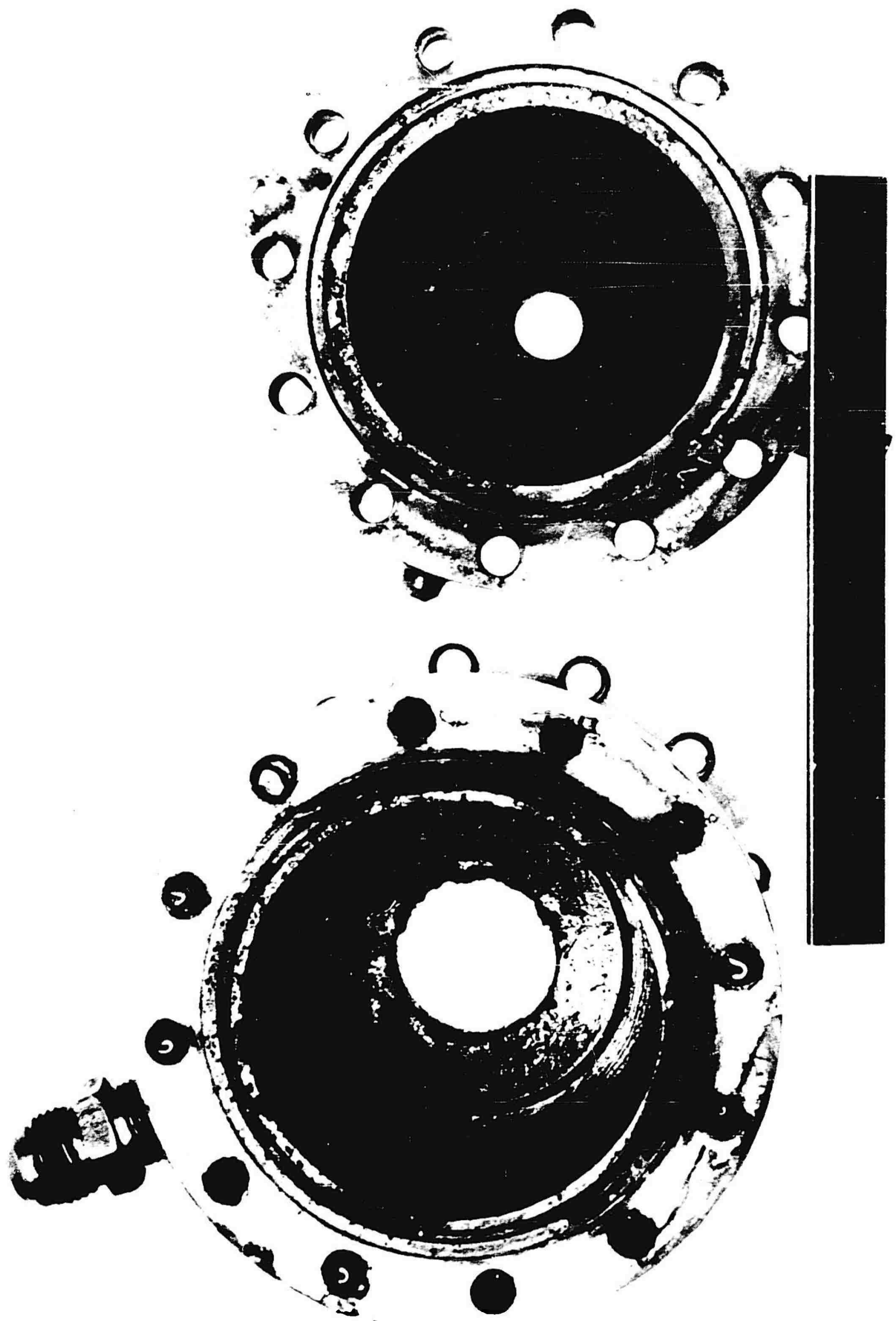
12[illegible]-0813

Solids Deposited on Exhaust Collector Screens During Run No. 17



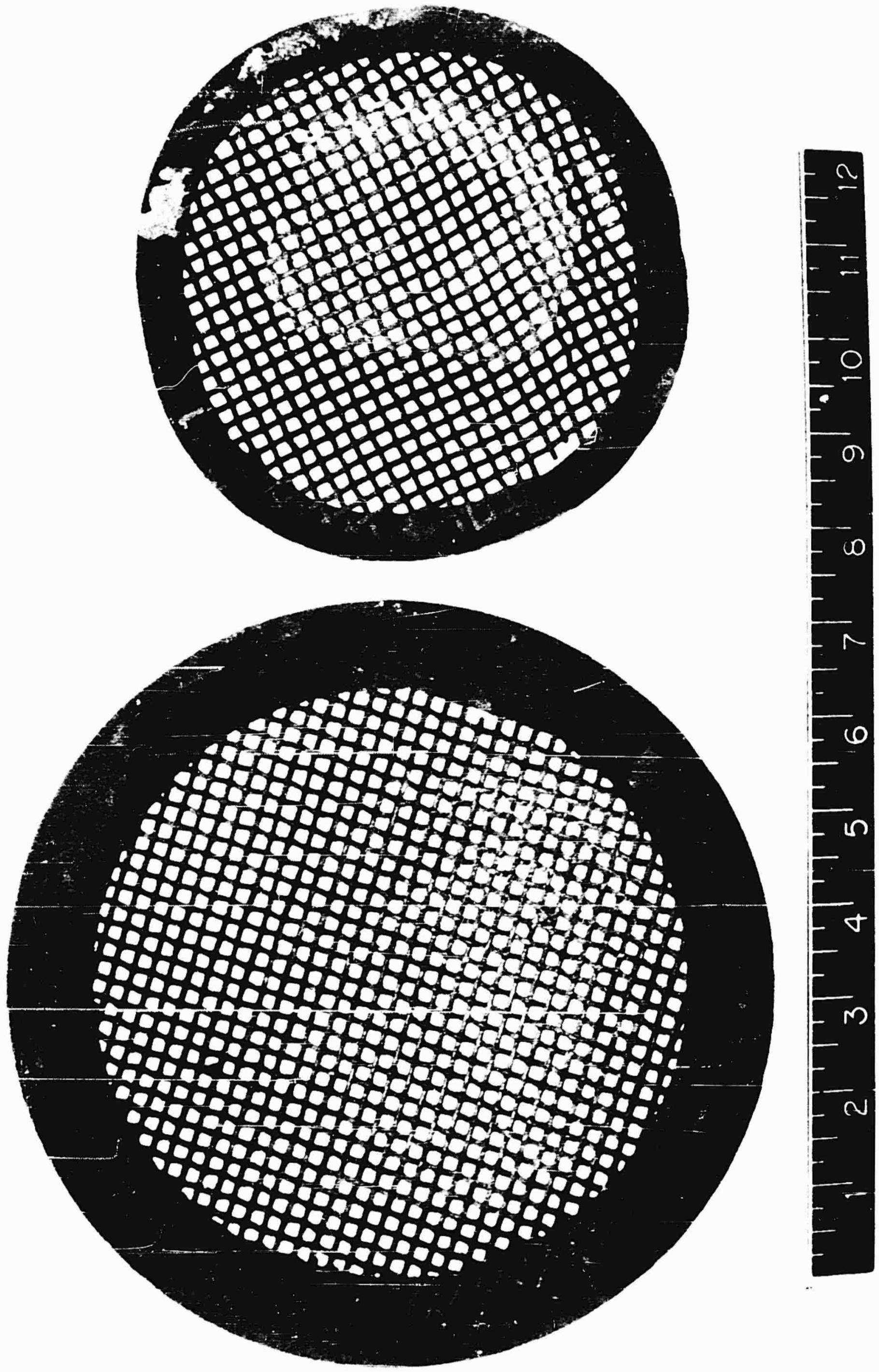
Solids Deposited on Exhaust Collector Screens During Run No. 25

357-346

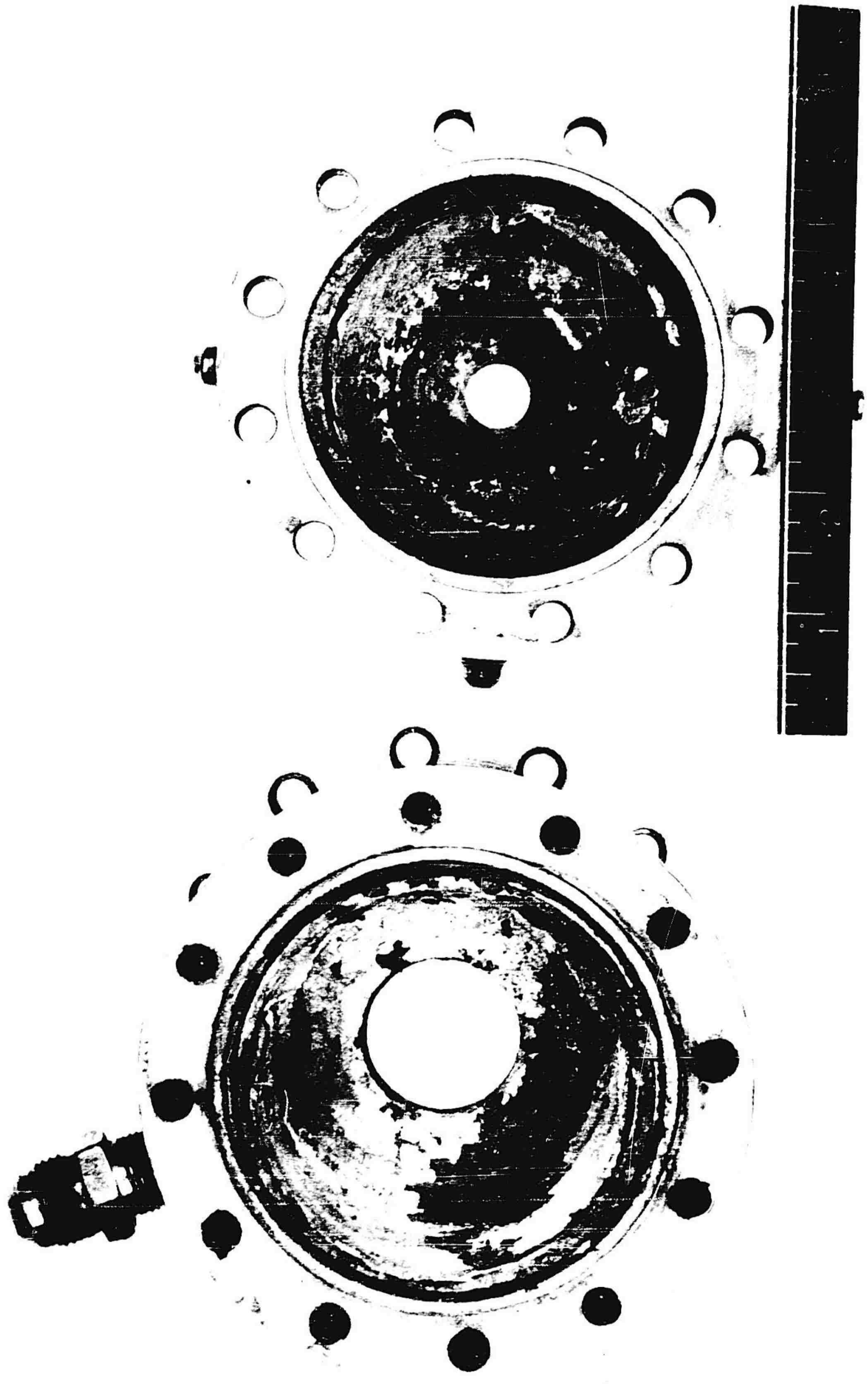


Solids Deposited in Combustion Chamber During Run No. 22

257-619

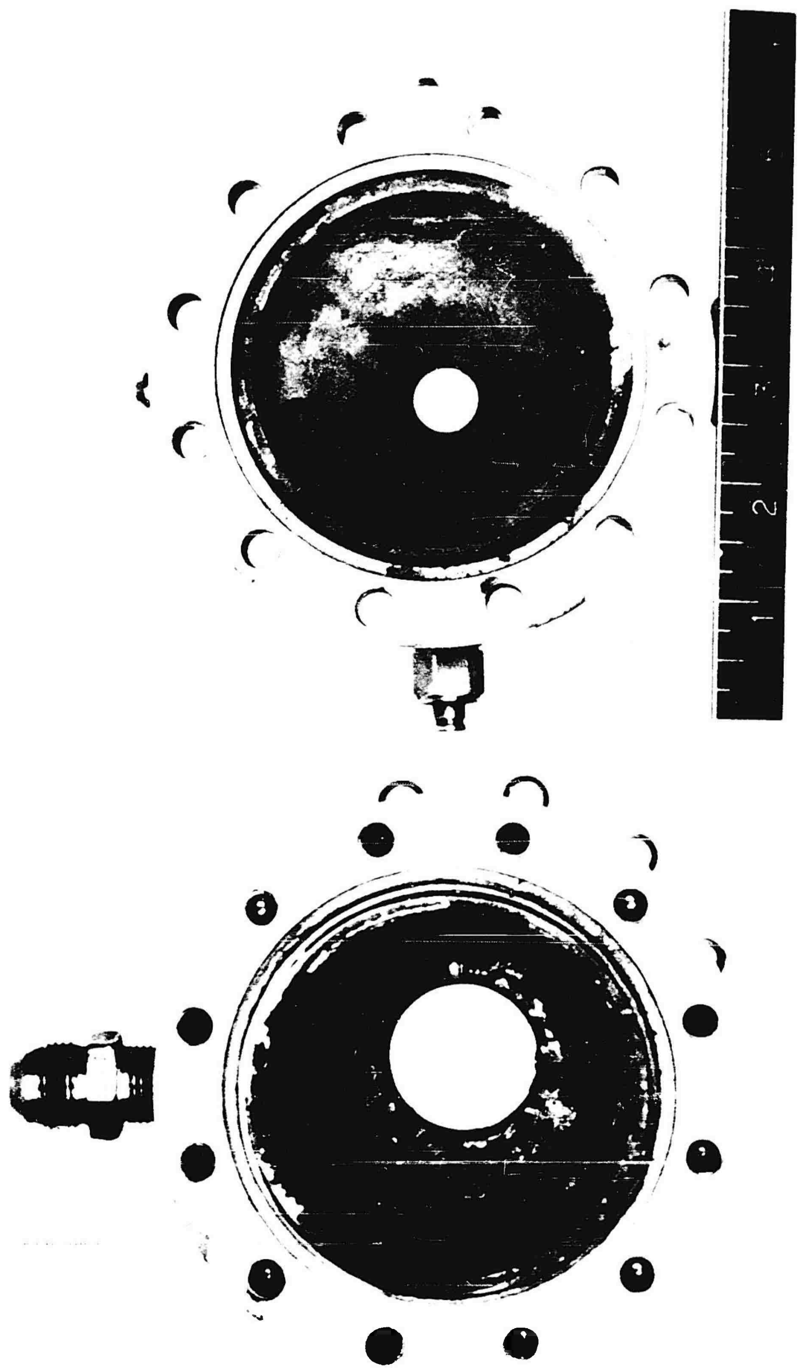


Solids Deposited on Exhaust Collector Screens During Run No. 22

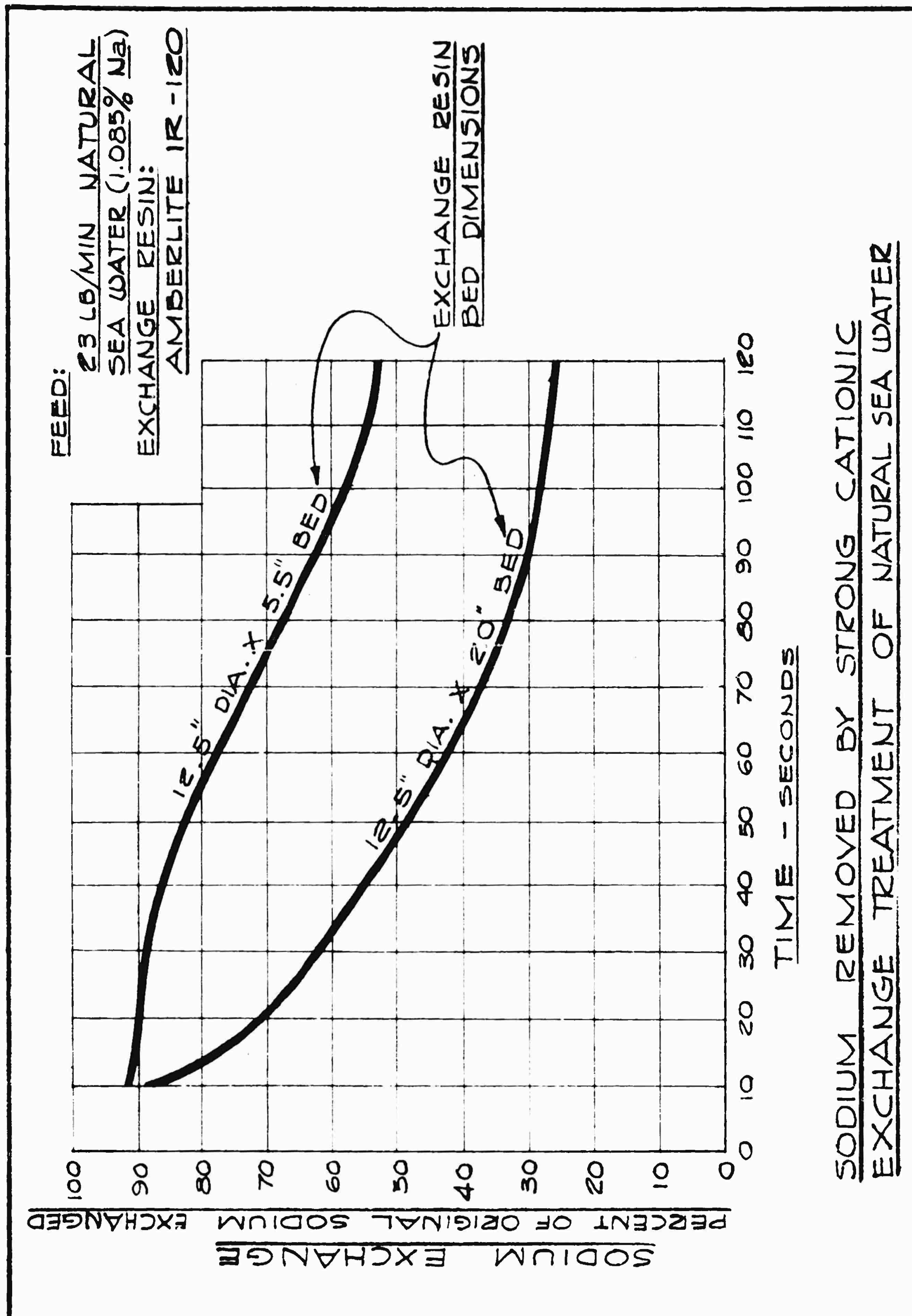


Solids Deposited in Combustion Chamber During Run No. 19

157-157



Solids Deposited in Combustion Chamber During Run No. 23


UEC-4702
FEED: 23 LB/MIN NATURAL SEA WATER (1.085% Na)
EXCHANGE RESIN: AMBERLITE IR-120
EXCHANGE RESIN BED DIMENSIONS
12.5" DIA. X 5.5" BED
12.5" DIA. X 20" BED
TIME - SECONDS
0 10 20 30 40 50 60 70 80 90 100 110 120
100 90 80 70 60 50 40 30 20 10 0
PERCENT OF ORIGINAL SODIUM EXCHANGED
SODIUM EXCHANGE
SODIUM REMOVED BY STRONG CATIONIC EXCHANGE TREATMENT OF NATURAL SEA WATER

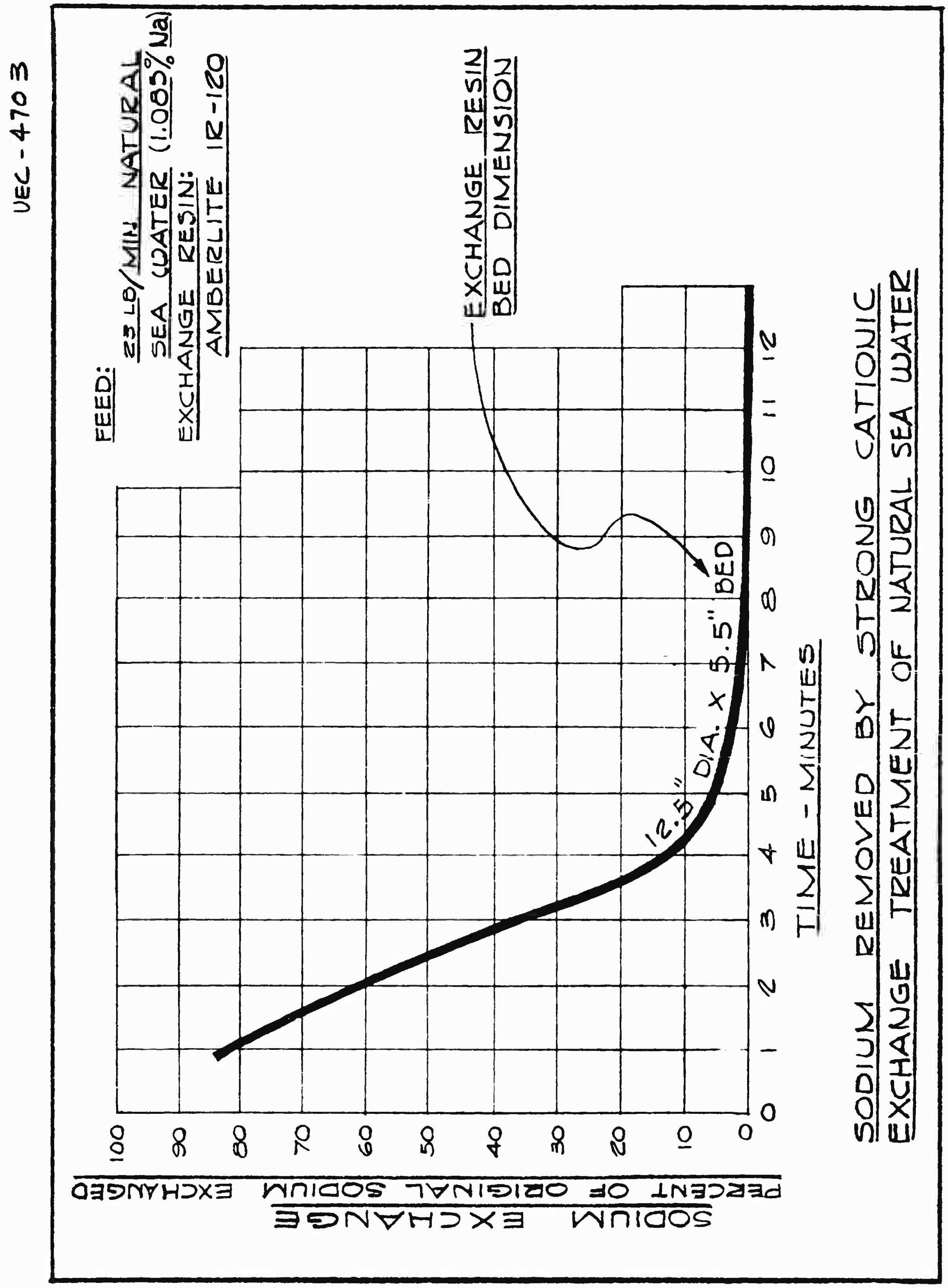
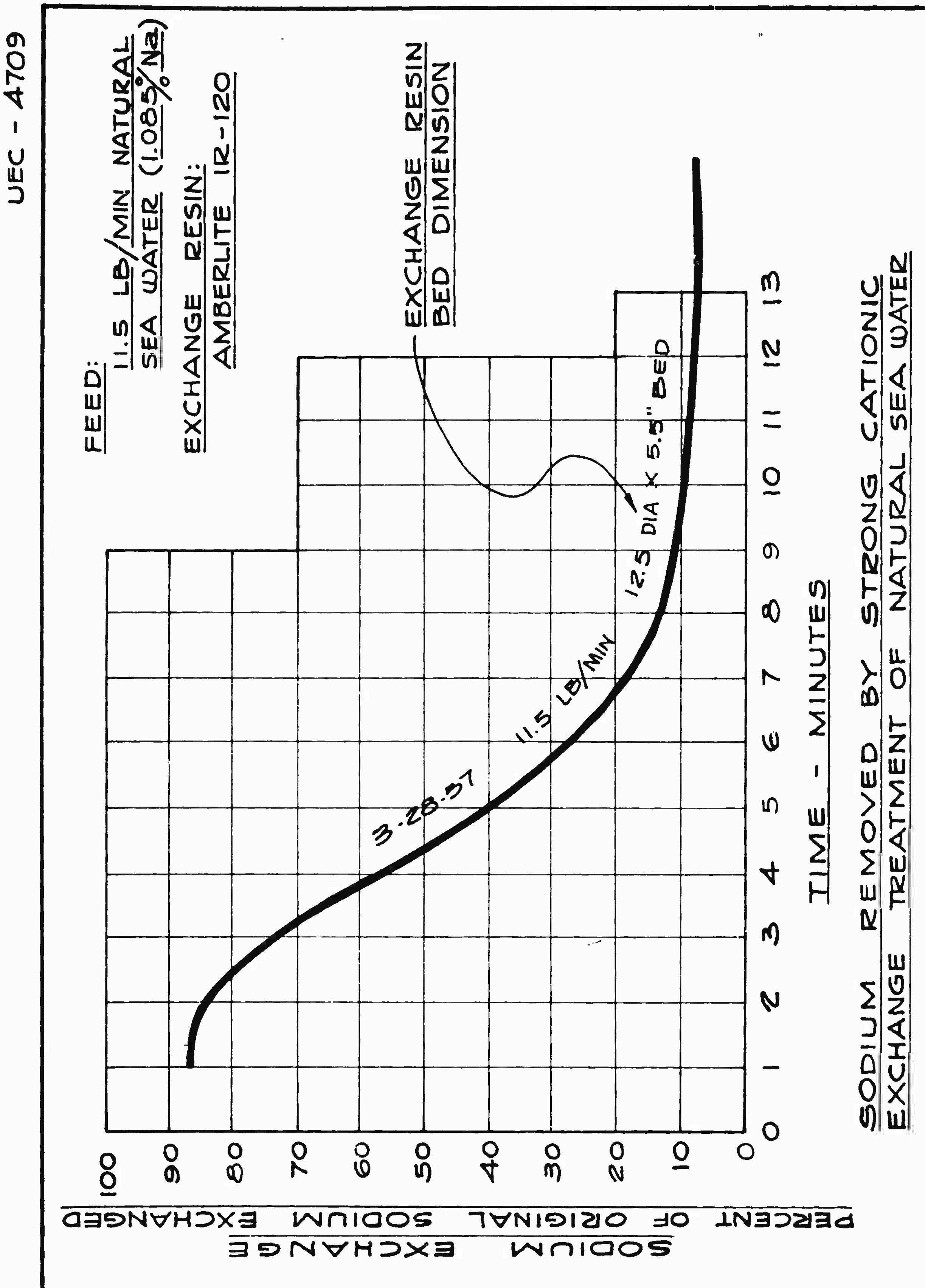
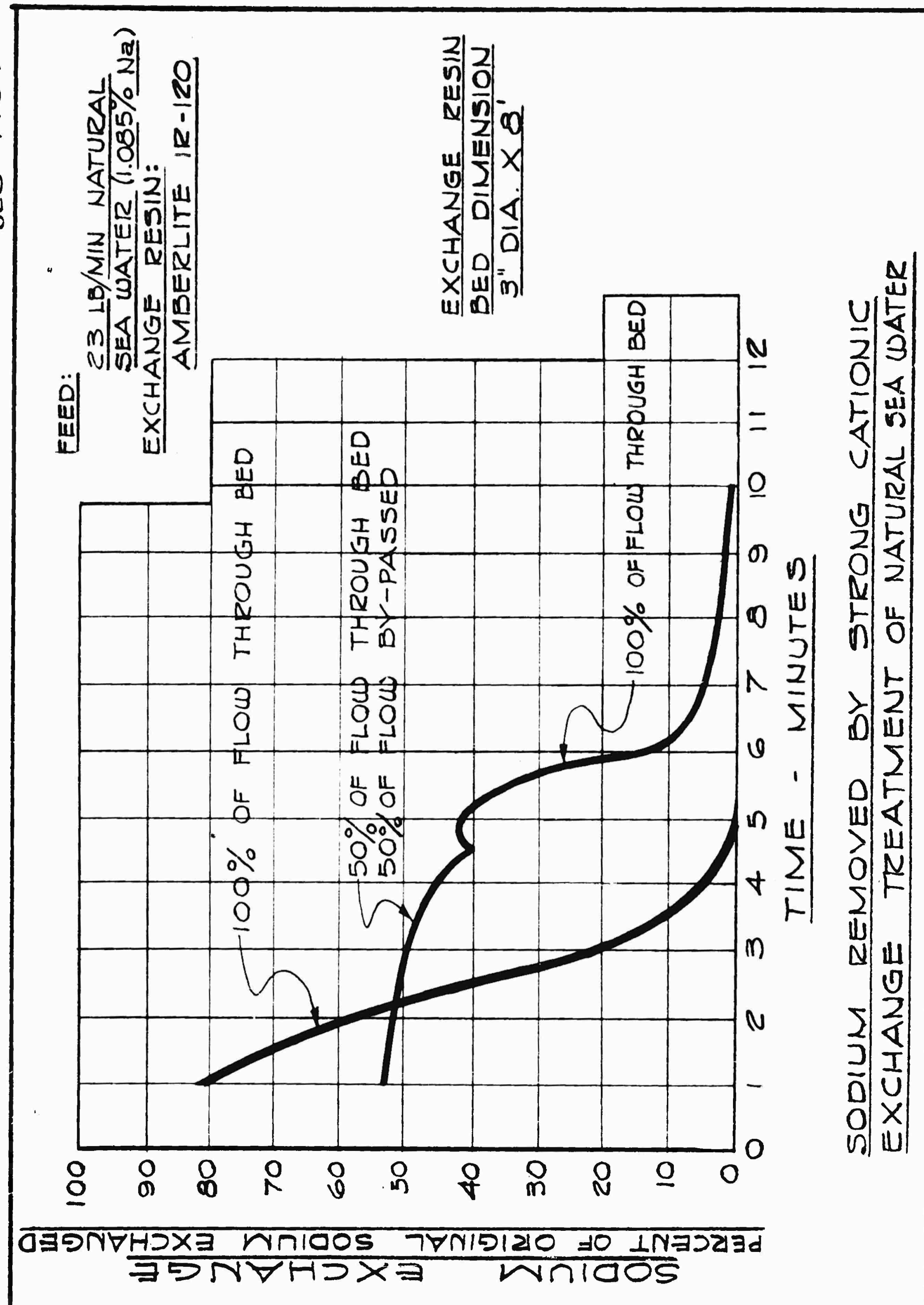

UEC-4703
FEED:
23 LB/MIN. NATURAL SEA WATER (1.085% Na)
EXCHANGE RESIN:
AMBERLITE IR-120
EXCHANGE RESIN BED DIMENSION
12.5" DIA. X 5.5" BED
0 1 2 3 4 5 6 7 8 9 10 11 12
TIME - MINUTES
0 10 20 30 40 50 60 70 80 90 100
PERCENT OF ORIGINAL SODIUM EXCHANGED
SODIUM EXCHANGE
SODIUM REMOVED BY STRONG CATIONIC EXCHANGE TREATMENT OF NATURAL SEA WATER

Figure 42


UEC - 4709
FEED: 11.5 LB/MIN NATURAL SEA WATER (1.085% Na)
EXCHANGE RESIN: AMBERLITE IR-120
EXCHANGE RESIN BED DIMENSION
12.5 DIA X 5.5" BED
11.5 LB/MIN
3-28-57
0 1 2 3 4 5 6 7 8 9 10 11 12 13
TIME - MINUTES
0 10 20 30 40 50 60 70 80 90 100
PERCENT OF ORIGINAL SODIUM EXCHANGED
SODIUM EXCHANGE
SODIUM REMOVED BY STRONG CATIONIC EXCHANGE TREATMENT OF NATURAL SEA WATER


UEC 4787
FEED:
23 LB/MIN NATURAL SEA WATER (1.085% Na)
EXCHANGE RESIN:
AMBERLITE IR-120
EXCHANGE RESIN BED DIMENSION
3" DIA. X 8'
100% OF FLOW THROUGH BED
50% OF FLOW THROUGH BED
50% OF FLOW BY-PASSED
100% OF FLOW THROUGH BED
0 1 2 3 4 5 6 7 8 9 10 11 12
TIME - MINUTES
100 90 80 70 60 50 40 30 20 10 0
PERCENT OF ORIGINAL SODIUM EXCHANGED
SODIUM EXCHANGE
SODIUM REMOVED BY STRONG CATIONIC
EXCHANGE TREATMENT OF NATURAL SEA WATER

Report No. 1307

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